

AP-42
SUPPLEMENT C
SEPTEMBER 1990

SUPPLEMENT C
TO
COMPILATION
OF
AIR POLLUTANT
EMISSION FACTORS
VOLUME I:
STATIONARY POINT
AND AREA SOURCES

This report has been reviewed by the Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, and has been approved for publication. Any mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

AP-42
Volume I
Supplement C

INSTRUCTIONS FOR INSERTING SUPPLEMENT C
INTO AP-42

- Pp. iii and iv replace same. New Publications In Series.
- Pp. v through viii replace same. New Contents.
- Pp. ix through xv replace same. New Key Word Index.
- Pp. 1.10-1 through 1.10-5 replace same. Major Revision.
- Pp. 2.1-1 through 2.1-20 replace 2.1-1 through 2.1-10. Major Revision.
- Pp. 2.5-1 through 2.5-13 replace 2.5-1 through 2.5-6. Major Revision.
- Add pp. 4.2.2.13-1 through 4.2.2.13-9. New Section.
- Add pp. 4.2.2.14-1 through 4.2.2.14-18. New Section.
- Pp. 5.19-1 through 5.19-24 replace 5.19-1 and 2. Major Revision.
- Pp. 7.6-5 and 6 replace same. Minor Revision.
- Pp. 7.10-19 through 7.10-21 replace same. Minor Revision.
- Pp. 10.1-5 and 6 replace same. Major Revision.
- Pp. 11.1-7 through 11.1-12 replace 11.1-7 through 11.1-11. Major Revision.
- Pp. 11.2.6-1 and 2 replace same. Minor Revision.
- Pp. 11.2.7-1 through 11.2.7-15 replace same. Minor Revision.
- Pp. 11.3-1 through 11.3-5 replace same. Editorial Change.
- Pp. C.2-5 and 6 replace same. Minor Revision.
- Pp. C.2-17 through C.2-19 replace C.2-17 and 18. Major Revision.
- Add pp. D-1 through D-8. New Appendix.
- Add pp. E-1 through E-8. New Appendix.

PUBLICATIONS IN SERIES

Issue		Date
COMPILATION OF AIR POLLUTANT EMISSION FACTORS (Fourth Edition)		9/85
SUPPLEMENT A		10/86
Introduction		
Section 1.1	Bituminous And Subbituminous Coal Combustion	
1.2	Anthracite Coal Combustion	
1.3	Fuel Oil Combustion	
1.4	Natural Gas Combustion	
1.6	Wood Waste Combustion In Boilers	
1.7	Lignite Combustion	
5.16	Sodium Carbonate	
7.1	Primary Aluminum Production	
7.2	Coke Production	
7.3	Primary Copper Smelting	
7.4	Ferroalloy Production	
7.5	Iron And Steel Production	
7.6	Primary Lead Smelting	
7.7	Zinc Smelting	
7.8	Secondary Aluminum Operations	
7.10	Gray Iron Foundries	
7.11	Secondary Lead Processing	
8.1	Asphaltic Concrete Plants	
8.3	Bricks And Related Clay Products	
8.6	Portland Cement Manufacturing	
8.10	Concrete Batching	
8.13	Glass Manufacturing	
8.15	Lime Manufacturing	
8.19.2	Crushed Stone Processing	
8.22	Taconite Ore Processing	
8.24	Western Surface Coal Mining	
10.1	Chemical Wood Pulping	
11.2.6	Industrial Paved Roads	
Appendix C.1	Particle Size Distribution Data And Sized Emission Factors For Selected Sources	
Appendix C.2	Generalized Particle Size Distributions	
SUPPLEMENT B		9/88
Section 1.1	Bituminous And Subbituminous Coal Combustion	
1.2	Anthracite Coal Combustion	
1.10	Residential Wood Stoves	
1.11	Waste Oil Combustion	
2.1	Refuse Combustion	
2.5	Sewage Sludge Incineration	
4.2	Surface Coating	
4.12	Polyester Resin Plastics Product Fabrication	

Section 5.15	Soap And Detergents
6.4	Grain Elevators And Processing Plants
8.15	Lime Manufacturing
8.19.2	Crushed Stone Processing
11.1	Wildfires And Prescribed Burning
11.2.1	Unpaved Roads
11.2.3	Aggregate Handling And Storage Piles
11.2.6	Industrial Paved Roads
11.2.7	Industrial Wind Erosion
Appendix C.3	Silt Analysis Procedures

SUPPLEMENT C

9/90

Section 1.10	Residential Wood Stoves
2.1	Refuse Combustion
2.5	Sewage Sludge Incineration
4.2.2.13	Magnetic Tape Manufacturing Industry
4.2.2.14	Surface Coating Of Plastic Parts For Business Machines
5.19	Synthetic Fiber Manufacturing
7.6	Primary Lead Smelting
7.10	Gray Iron Foundries
10.1	Chemical Wood Pulping
11.1	Wildfires And Prescribed Burning
11.2.6	Industrial Paved Roads
11.2.7	Industrial Wind Erosion
11.3	Explosives Detonation
Appendix C.2	Generalized Particle Size Distributions
Appendix D	Procedures For Sampling Surface/Bulk Dust Loading
Appendix E	Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples

CONTENTS

	Page
INTRODUCTION	1
1. EXTERNAL COMBUSTION SOURCES	1.1-1
1.1 Bituminous Coal Combustion	1.1-1
1.2 Anthracite Coal Combustion	1.2-1
1.3 Fuel Oil Combustion	1.3-1
1.4 Natural Gas Combustion	1.4-1
1.5 Liquified Petroleum Gas Combustion	1.5-1
1.6 Wood Waste Combustion In Boilers	1.6-1
1.7 Lignite Combustion	1.7-1
1.8 Bagasse Combustion In Sugar Mills	1.8-1
1.9 Residential Fireplaces	1.9-1
1.10 Residential Wood Stoves	1.10-1
1.11 Waste Oil Combustion	1.11-1
2. SOLID WASTE DISPOSAL	2.0-1
2.1 Refuse Combustion	2.1-1
2.2 Automobile Body Incineration	2.2-1
2.3 Conical Burners	2.3-1
2.4 Open Burning	2.4-1
2.5 Sewage Sludge Incineration	2.5-1
3. STATIONARY INTERNAL COMBUSTION SOURCES	3.0-1
Glossary Of Terms	Vol. II
Highway Vehicles	Vol. II
Off Highway Mobile Sources	Vol. II
3.1 Stationary Gas Turbines For Electric Utility Power Plants	3.1-1
3.2 Heavy Duty Natural Gas Fired Pipeline Compressor Engines	3.2-1
3.3 Gasoline And Diesel Industrial Engines	3.3-1
3.4 Stationary Large Bore And Dual Fuel Engines	3.4-1
4. EVAPORATION LOSS SOURCES	4.1-1
4.1 Dry Cleaning	4.1-1
4.2 Surface Coating	4.2-1
4.3 Storage Of Organic Liquids	4.3-1
4.4 Transportation And Marketing Of Petroleum Liquids	4.4-1
4.5 Cutback Asphalt, Emulsified Asphalt And Asphalt Cement ..	4.5-1
4.6 Solvent Degreasing	4.6-1
4.7 Waste Solvent Reclamation	4.7-1
4.8 Tank And Drum Cleaning	4.8-1
4.9 Graphic Arts	4.9-1
4.10 Commercial/Consumer Solvent Use	4.10-1
4.11 Textile Fabric Printing	4.11-1
4.12 Polyester Resin Plastics Product Fabrication	4.12-1

	Page
5. CHEMICAL PROCESS INDUSTRY	5.1-1
5.1 Adipic Acid	5.1-1
5.2 Synthetic Ammonia	5.2-1
5.3 Carbon Black	5.3-1
5.4 Charcoal	5.4-1
5.5 Chlor-Alkali	5.5-1
5.6 Explosives	5.6-1
5.7 Hydrochloric Acid	5.7-1
5.8 Hydrofluoric Acid	5.8-1
5.9 Nitric Acid	5.9-1
5.10 Paint And Varnish	5.10-1
5.11 Phosphoric Acid	5.11-1
5.12 Phthalic Anhydride	5.12-1
5.13 Plastics	5.13-1
5.14 Printing Ink	5.14-1
5.15 Soap And Detergents	5.15-1
5.16 Sodium Carbonate	5.16-1
5.17 Sulfuric Acid	5.17-1
5.18 Sulfur Recovery	5.18-1
5.19 Synthetic Fibers	5.19-1
5.20 Synthetic Rubber	5.20-1
5.21 Terephthalic Acid	5.21-1
5.22 Lead Alkyl	5.22-1
5.23 Pharmaceuticals Production	5.23-1
5.24 Maleic Anhydride	5.24-1
6. FOOD AND AGRICULTURAL INDUSTRY	6.1-1
6.1 Alfalfa Dehydrating	6.1-1
6.2 Coffee Roasting	6.2-1
6.3 Cotton Ginning	6.3-1
6.4 Grain Elevators And Processing Plants	6.4-1
6.5 Fermentation	6.5-1
6.6 Fish Processing	6.6-1
6.7 Meat Smokehouses	6.7-1
6.8 Ammonium Nitrate Fertilizers	6.8-1
6.9 Orchard Heaters	6.9-1
6.10 Phosphate Fertilizers	6.10-1
6.11 Starch Manufacturing	6.11-1
6.12 Sugar Cane Processing	6.12-1
6.13 Bread Baking	6.13-1
6.14 Urea	6.14-1
6.15 Beef Cattle Feedlots	6.15-1
6.16 Defoliation And Harvesting Of Cotton	6.16-1
6.17 Harvesting Of Grain	6.17-1
6.18 Ammonium Sulfate	6.18-1
7. METALLURGICAL INDUSTRY	7.1-1
7.1 Primary Aluminum Production	7.1-1
7.2 Coke Production	7.2-1
7.3 Primary Copper Smelting	7.3-1
7.4 Ferroalloy Production	7.4-1

	Page
7.5 Iron And Steel Production	7.5-1
7.6 Primary Lead Smelting	7.6-1
7.7 Zinc Smelting	7.7-1
7.8 Secondary Aluminum Operations	7.8-1
7.9 Secondary Copper Smelting And Alloying	7.9-1
7.10 Gray Iron Foundries	7.10-1
7.11 Secondary Lead Processing	7.11-1
7.12 Secondary Magnesium Smelting	7.12-1
7.13 Steel Foundries	7.13-1
7.14 Secondary Zinc Processing	7.14-1
7.15 Storage Battery Production	7.15-1
7.16 Lead Oxide And Pigment Production	7.16-1
7.17 Miscellaneous Lead Products	7.17-1
7.18 Leadbearing Ore Crushing And Grinding	7.18-1
8. MINERAL PRODUCTS INDUSTRY	8.1-1
8.1 Asphaltic Concrete Plants	8.1-1
8.2 Asphalt Roofing	8.2-1
8.3 Bricks And Related Clay Products	8.3-1
8.4 Calcium Carbide Manufacturing	8.4-1
8.5 Castable Refractories	8.5-1
8.6 Portland Cement Manufacturing	8.6-1
8.7 Ceramic Clay Manufacturing	8.7-1
8.8 Clay And Fly Ash Sintering	8.8-1
8.9 Coal Cleaning	8.9-1
8.10 Concrete Batching	8.10-1
8.11 Glass Fiber Manufacturing	8.11-1
8.12 Frit Manufacturing	8.12-1
8.13 Glass Manufacturing	8.13-1
8.14 Gypsum Manufacturing	8.14-1
8.15 Lime Manufacturing	8.15-1
8.16 Mineral Wool Manufacturing	8.16-1
8.17 Perlite Manufacturing	8.17-1
8.18 Phosphate Rock Processing	8.18-1
8.19 Construction Aggregate Processing	8.19-1
8.20 [Reserved]	8.20-1
8.21 Coal Conversion	8.21-1
8.22 Taconite Ore Processing	8.22-1
8.23 Metallic Minerals Processing	8.23-1
8.24 Western Surface Coal Mining	8.24-1
9. PETROLEUM INDUSTRY	9.1-1
9.1 Petroleum Refining	9.1-1
9.2 Natural Gas Processing	9.2-1
10. WOOD PRODUCTS INDUSTRY	10.1-1
10.1 Chemical Wood Pulping	10.1-1
10.2 Pulpboard	10.2-1
10.3 Plywood Veneer And Layout Operations	10.3-1
10.4 Woodworking Waste Collection Operations	10.4-1

	Page
11. MISCELLANEOUS SOURCES	11.1-1
11.1 Wildfires And Prescribed Burning	11.1-1
11.2 Fugitive Dust Sources	11.2-1
11.3 Explosives Detonation	11.3-1
APPENDIX A Miscellaneous Data And Conversion Factors	A-1
APPENDIX B (Reserved For Future Use)	
APPENDIX C.1 Particle Size Distribution Data And Sized Emission Factors For Selected Sources	C.1-1
APPENDIX C.2 Generalized Particle Size Distributions	C.2-1
APPENDIX C.3 Silt Analysis Procedures	C.3-1
APPENDIX D Procedures For Sampling Surface/Bulk Dust Loading	D-1
APPENDIX E Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples	E-1

KEY WORD INDEX

Acid	
Adipic.....	5.1
Hydrochloric.....	5.7
Hydrofluoric.....	5.8
Phosphoric.....	5.11
Sulfuric.....	5.17
Terephthalic.....	5.21
Adipic Acid.....	5.1
Aggregate, Construction.....	8.19
Aggregate Storage Piles	
Fugitive Dust Sources.....	11.2
Agricultural Tilling	
Fugitive Dust Sources.....	11.2
Alfalfa Dehydrating.....	6.1
Alkali, Chlor-.....	5.5
Alloys	
Ferroalloy Production.....	7.4
Secondary Copper Smelting And Alloying.....	7.9
Aluminum	
Primary Aluminum Production.....	7.1
Secondary Aluminum Operations.....	7.8
Ammonia, Synthetic.....	5.2
Ammonium Nitrate Fertilizers.....	6.8
Anhydride, Phthalic.....	5.12
Anthracite Coal Combustion.....	1.2
Ash	
Fly Ash Sintering.....	8.8
Asphalt	
Cutback Asphalt, Emulsified Asphalt And Asphalt Cement.....	4.5
Roofing.....	8.2
Asphaltic Concrete Plants.....	8.1
Automobile Body Incineration.....	2.2
Bagasse Combustion In Sugar Mills.....	1.8
Baking, Bread.....	6.13
Bark	
Wood Waste Combustion In Boilers.....	1.6
Batching, Concrete.....	8.10
Battery	
Storage Battery Production.....	7.15
Beer Production	
Fermentation.....	6.5
Bituminous Coal Combustion.....	1.1
Bread Baking.....	6.13
Bricks And Related Clay Products.....	8.3
Burners, Conical (Teepee).....	2.3
Burning, Open.....	2.4

Calcium Carbide Manufacturing.....	8.4
Cane	
Sugar Cane Processing.....	6.12
Carbon Black.....	5.3
Carbonate	
Sodium Carbonate Manufacturing.....	5.16
Castable Refractories.....	8.5
Cattle	
Beef Cattle Feedlots.....	6.15
Cement	
Asphalt.....	4.5
Portland Cement Manufacturing.....	8.6
Ceramic Clay Manufacturing.....	8.7
Charcoal.....	5.4
Chemical Wood Pulping.....	10.1
Chlor-Alkali.....	5.5
Clay	
Bricks And Related Clay Products.....	8.3
Ceramic Clay Manufacturing.....	8.7
Clay And Fly Ash Sintering.....	8.8
Cleaning	
Coal.....	8.9
Dry.....	4.1
Tank And Drum.....	4.8
Coal	
Anthracite Coal Combustion.....	1.2
Bituminous Coal Combustion.....	1.1
Cleaning.....	8.9
Conversion.....	8.21
Coating, Surface.....	4.2
Coffee Roasting.....	6.2
Coke Manufacturing.....	7.2
Combustion	
Anthracite Coal.....	1.2
Bagasse, In Sugar Mills.....	1.8
Bituminous Coal.....	1.1
Fuel Oil.....	1.3
Internal.....	Vol. II
Lignite.....	1.7
Liquified Petroleum Gas.....	1.5
Natural Gas.....	1.4
Orchard Heaters.....	6.9
Residential Fireplaces.....	1.9
Waste Oil.....	1.11
Wood Stoves.....	1.10
Concrete	
Asphaltic Concrete Plants.....	8.1
Concrete Batching.....	8.10
Conical (Teepee) Burners.....	2.3
Construction Aggregate.....	8.19
Construction Operations	
Fugitive Dust Sources.....	11.2
Conversion, Coal.....	8.21
Wood Waste In Boilers.....	1.6

Copper	
Primary Copper Smelting.....	7.3
Secondary copper Smelting And Alloying.....	7.9
Cotton	
Defoliation And Harvesting.....	6.16
Ginning.....	6.3
Dacron	
Synthetic Fibers.....	5.19
Defoliation, Cotton.....	6.16
Degreasing, Solvent.....	4.6
Dehydrating, Alfalfa.....	6.1
Detergents	
Soap And Detergents.....	5.15
Detonation, Explosives.....	11.3
Drum	
Tank And Drum Cleaning.....	4.8
Dry Cleaning.....	4.1
Dual Fuel Engines, Stationary.....	3.4
Dust	
Fugitive Dust Sources.....	11.2
Dust Loading Sampling Procedures.....	App. D
Dust Loading Analysis.....	App. E
Electric Utility Power Plants, Gas.....	3.1
Elevators, Feed And Grain Mills.....	6.4
Explosives.....	5.6
Explosives Detonation.....	11.3
Feed	
Beef Cattle Feedlots.....	6.15
Feed And Grain Mills And Elevators.....	6.4
Fermentation.....	6.5
Fertilizers	
Ammonium Nitrate.....	6.8
Phosphate.....	6.10
Ferroalloy Production.....	7.4
Fiber	
Glass Fiber Manufacturing.....	8.11
Fiber, Synthetic.....	5.19
Fires	
Forest Wildfires And Prescribed Burning.....	11.1
Fireplaces, Residential.....	1.9
Fish Processing.....	6.6
Fly Ash	
Clay And Fly Ash Sintering.....	8.8
Foundries	
Gray Iron Foundries.....	7.10
Steel Foundries.....	7.13
Frit Manufacturing.....	8.12
Fuel Oil Combustion.....	1.3
Fugitive Dust Sources.....	11.2

Gas Combustion, Liquified Petroleum.....	1.5
Gas, Natural	
Natural Gas Combustion.....	1.4
Natural Gas Processing.....	9.2
Gasoline/Diesel Engines.....	3.3
Ginning, Cotton.....	6.3
Glass Manufacturing.....	8.13
Glass Fiber Manufacturing.....	8.11
Grain	
Feed And Grain Mills And Elevators.....	6.4
Harvesting Of Grain.....	6.17
Gravel	
Sand And Gravel Processing.....	8.19
Gray Iron Foundries.....	7.10
Gypsum Manufacturing.....	8.14
Harvesting	
Cotton.....	6.16
Grain.....	6.17
Heaters, Orchard.....	6.9
Hydrochloric Acid.....	5.7
Hydrofluoric Acid.....	5.8
Incineration	
Automobile Body.....	2.2
Conical (Teepee).....	2.3
Refuse.....	2.1
Sewage Sludge.....	2.5
Industrial Engines, Gasoline And Diesel.....	3.3
Ink, Printing.....	5.14
Internal Combustion Engines	
Highway Vehicles.....	Vol. II
Off Highway Mobile Sources.....	Vol. II
Off Highway Stationary Sources.....	3.0
Iron	
Ferroalloy Production.....	7.4
Gray Iron Foundries.....	7.10
Iron And Steel Mills.....	7.5
Taconite Ore Processing.....	8.22
Large Bore Engines.....	3.4
Lead	
Leadbearing Ore Crushing And Grinding.....	7.18
Miscellaneous Lead Products.....	7.17
Primary Lead Smelting.....	7.6
Secondary Lead Smelting.....	7.11
Lead Alkyl.....	5.22
Lead Oxide And Pigment Production.....	7.16
Leadbearing Ore Crushing And Grinding.....	7.18
Lignite Combustion.....	1.7
Lime Manufacturing.....	8.15
Liquified Petroleum Gas Combustion.....	1.5

Magnesium	
Secondary Magnesium Smelting.....	7.12
Magnetic Tape Manufacturing.....	4.2
Maleic Anhydride.....	5.24
Marketing	
Transportation And Marketing Of Petroleum Liquids.....	4.4
Meat Smokehouses.....	6.7
Mineral Wool Manufacturing.....	8.16
Mobile Sources	
Highway.....	Vol. II
Off Highway.....	Vol. II
Natural Gas Combustion.....	1.4
Natural Gas Fired Pipeline Compressors.....	3.2
Natural Gas Processing.....	9.2
Nitric Acid Manufacturing.....	5.9
Off Highway Mobile Sources.....	Vol. II
Off Highway Stationary Sources.....	3.0
Oil	
Fuel Oil Combustion.....	1.3
Waste Oil Combustion.....	1.11
Open Burning.....	2.4
Orchard Heaters.....	6.9
Ore Processing	
Leadbearing Ore Crushing And Grinding.....	7.18
Taconite.....	8.22
Organic Liquids, Storage.....	4.3
Paint And Varnish Manufacturing.....	5.10
Paved Roads	
Fugitive Dust Sources.....	11.2
Perlite Manufacturing.....	8.17
Petroleum	
Liquified Petroleum Gas Combustion.....	1.5
Refining.....	9.1
Storage Of Organic Liquids.....	4.3
Transportation And Marketing Of Petroleum Liquids.....	4.4
Pharmaceuticals Production.....	5.23
Phosphate Fertilizers.....	6.10
Phosphate Rock Processing.....	8.18
Phosphoric Acid.....	5.11
Phthalic Anhydride.....	5.12
Pigment	
Lead Oxide And Pigment Production.....	7.16
Pipeline Compressors.....	3.2
Plastics.....	5.13
Plywood Veneer And Layout Operations.....	10.3
Polyester Resin Plastics Product Fabrication.....	4.12
Portland Cement Manufacturing.....	8.6
Prescribed Burning.....	11.1
Printing Ink.....	5.14
Pulpboard.....	10.2
Pulping, Chemical Wood.....	10.1

Reclamation, Waste Solvent.....	4.7
Recovery, Sulfur.....	5.18
Refractories, Castable.....	8.5
Residential Fireplaces.....	1.9
Roads, Paved	
Fugitive Dust Sources.....	11.2
Roads, Unpaved	
Fugitive Dust Sources.....	11.2
Roasting Coffee.....	6.2
Rock	
Phosphate Rock Processing.....	8.18
Roofing, Asphalt.....	8.2
Rubber, Synthetic.....	5.20
Sand And Gravel Processing.....	8.19
Sewage Sludge Incineration.....	2.5
Sintering, Clay And Fly Ash.....	8.8
Smelting	
Primary Copper Smelting.....	7.3
Primary Lead Smelting.....	7.6
Secondary Copper Smelting And Alloying.....	7.9
Secondary Lead Smelting.....	7.11
Secondary Magnesium Smelting.....	7.12
Zinc Smelting.....	7.7
Smokehouses, Meat.....	6.7
Soap And Detergent Manufacturing.....	5.15
Sodium Carbonate Manufacturing.....	5.16
Solvent	
Commercial/Consumer Use.....	4.10
Solvent Degreasing.....	4.6
Waste Solvent Reclamation.....	4.7
Starch Manufacturing.....	6.11
Stationary Gas Turbines.....	3.1
Stationary Sources, Off Highway.....	3.0
Steel	
Iron And Steel Mills.....	7.5
Steel Foundries.....	7.13
Storage Battery Production.....	7.15
Storage Of Organic Liquids.....	4.3
Sugar Cane Processing.....	6.12
Sugar Mills, Bagasse Combustion In.....	1.8
Sulfur Recovery.....	5.18
Sulfuric Acid.....	5.17
Surface Coating.....	4.2
Synthetic Ammonia.....	5.2
Synthetic Fiber.....	5.19
Synthetic Rubber.....	5.20
Taconite Ore Processing.....	8.22
Tank And Drum Cleaning.....	4.8
Tape, Magnetic.....	4.2
Terephthalic Acid.....	5.21

Tilling, Agricultural	
Fugitive Dust Sources.....	11.2
Transportation And Marketing Of Petroleum Liquids.....	4.4
Turbine Engines, Natural Gas.....	3.1
Unpaved Roads	
Fugitive Dust Sources.....	11.2
Urea.....	6.14
Varnish	
Paint And Varnish Manufacturing.....	5.10
Vehicles, Highway And Off Highway.....	Vol. II
Waste Solvent Reclamation.....	4.7
Waste Oil Combustion.....	1.11
Whiskey Production	
Fermentation.....	6.5
Wildfires, Forest.....	11.1
Wine Making	
Fermentation.....	6.5
Wood Pulping, Chemical.....	10.1
Wood Stoves.....	1.10
Wood Waste Combustion In Boilers.....	1.6
Woodworking Waste Collection Operations.....	10.4
Zinc	
Secondary Zinc Processing.....	7.14
Smelting.....	7.7

1.10 RESIDENTIAL WOOD STOVES

1.10.1 General¹⁻³

Wood stoves are commonly used as space heaters in residences to supplement conventional heating systems. They are increasingly found as the primary source of residential heat.

Because of differences in both the magnitude and the composition of emissions from wood stoves, four different categories of stoves should be considered when estimating emissions:

- the conventional noncatalytic wood stove,
- the noncatalytic low emitting wood stove,
- the pellet fired noncatalytic wood stove, and
- the catalytic wood stove.

Among these categories, there are many variations in wood stove design and operation characteristics.

The conventional stove category comprises all stoves without catalytic combustors not included in the other noncatalytic categories. Stoves of many different airflow designs, such as updraft, downdraft, crossdraft, and S-flow, may be in this category.

"Noncatalytic low emitting" wood stoves are those units properly installed, having no catalyst and meeting EPA certification standards as of July 1, 1990.¹

Pellet fired stoves are those fueled with pellets of sawdust, wood products, and other biomass materials pressed into manageable shape and size. These stoves have a specially designed or modified grate to accommodate this type of fuel.

Catalytic stoves are equipped with a ceramic or metal honeycomb device, called a combustor or converter, that is coated with a noble metal such as platinum or palladium. The catalyst material reduces the ignition temperature of the unburned hydrocarbons and carbon monoxide in the exhaust gases, thus augmenting their ignition and combustion at normal stove operating temperatures. As these components of the gases burn, the temperature inside the catalyst increases to a point where the ignition of the gases is essentially selfsustaining. The particulate emissions data in Table 1.10 represent the field operation emissions expected from properly installed catalytic wood heaters meeting the EPA July 1, 1990 certification standards.

1.10.2 Emissions⁴⁻¹⁵

The combustion and pyrolysis of wood in wood stoves produce atmospheric emissions of particulate, carbon monoxide, nitrogen oxides, organic compounds, mineral residues, and to a lesser extent, sulfur oxides. The quantities and types of emissions are highly variable and depend on a number of factors, including the stages of the combustion cycle. During initial stages of burning, after a new wood charge is introduced, emissions increase dramatically and are primarily volatile organic compounds (VOC). After the initial period of high burn rate, there is a charcoal stage of the burn cycle, characterized by a slower burn rate and decreased emission rates. Emission rates during this stage are cyclical, characterized by relatively long periods of low emissions with shorter episodes of emission spikes.

Particulate emissions are defined in this document as the total catch measured by the EPA Method 5H (Oregon Method 7) sampling train.¹ A small portion of wood stove particulate emissions includes "solid" particles of elemental carbon and wood. The vast majority of particulate emissions is condensed organic products of incomplete combustion equal to or less than 10 micrometers in aerodynamic diameter (PM₁₀). The particulate emission values shown in Table 1.10-1 represent estimates of emissions produced by wood heaters expected to be available over the next few years as cleaner, more reliable wood stoves are manufactured to meet the New Source Performance Standards.¹ These emission values are derived from limited field test data⁷ from studies of the best available wood stove control technology. Still, there is a potential for higher emissions from some wood stove models.

In addition, the values for particulate and carbon monoxide emissions on the table reflect tests of new units. Control devices on wood stoves may exhibit reduced control efficiency over a period of operation, resulting in increased emissions 3 to 5 years after installation. For catalyst equipped wood heaters, the potential for control degradation is probably on the order of 10 to 30 percent after 3 years of operation. Control degradation for any stoves, including low emitting noncatalyst wood stoves may also occur, as a result of deteriorated seals and gaskets, misaligned baffles and bypass mechanisms, broken refractory, or other damaged functional components. The increase in emissions resulting from such control degradation has not been quantified, but can be significant.

Although reported particle size data are scarce, one reference states that 95 percent of the particles in the emissions from a wood stove were less than 0.4 micrometers in size.⁴

Sulfur oxides are formed by oxidation of sulfur in the wood. Nitrogen oxides are formed by oxidation of fuel and atmospheric nitrogen. Mineral constituents, such as potassium and sodium compounds, are also released from the wood matrix during combustion. The high levels of organic compound and carbon monoxide emissions result from incomplete combustion of the wood.

TABLE 1.10-1. EMISSION FACTORS FOR COMBUSTION IN RESIDENTIAL WOOD STOVES

Stove type	Particulate ^{a,b,c} ≤10 µm	Carbon monoxide ^b	Nitrogen oxides ^b	Sulfur oxides ^b	Volatile organics ^d		Efficiency ^e (%)
					Methane	Nonmethane	
Conventional units	15 (30)	140 (270)	1.4 (2.8) ^f	0.2 (0.4)	32 (64)	14 (28)	52
Phase II units ^g							
Catalytic	6.6 (13)	39 (78)	1.0 (2.0)	0.2 (0.4)	13 (26)	8.6 (17)	72
Noncatalytic	9.6 (19)	130 (260)	-	0.2 (0.4)	-	-	63
Pellet fired	1.6 (3.2)	18 (36)	6.9 ^h (14)	0.2 (0.4)	-	-	78

^aPhase II units are subject to 10 to 30% degradation within the first 3 years of use. Units are g/kg (lb/ton) of dry wood burned. Dash = no data.

^bReferences 2-8. Emission Factor Rating for particulate, CO and SO_x; C; for NO_x; E. Based on field tests described in Reference 8.

^cReference 1. Defined as equivalent to total catch by EPA Method 5H (Oregon Method 7) train.

^dReferences 6,9. Emission Factor Rating: E. Calculated by adding the estimated mass of simple hydrocarbon material C1 - C7 data to total chromatographable organics.

^eReference 1. Overall efficiency represents sum of combustion and transfer efficiencies, and values represent averages of laboratory test results.

^fReferences 12,15. Emission Factor Rating: C.

^gReference 1. Expected from wood heaters meeting NSPS after July 1, 1990.

^hReference 6. Based on a single data point.

Organic constituents of wood smoke vary considerably in both type and volatility. These constituents include simple hydrocarbons of carbon number 1 through 7 (C1 - C7), which exist as gases or which volatilize at ambient conditions, and complex low volatility substances that condense at ambient conditions. These low volatility condensible materials generally are considered to have boiling points below 300°C (572°F).

Polycyclic organic matter (POM) is an important component of the condensible fraction of wood smoke. POM contains a wide range of compounds, including organic compounds formed by the combination of free radical species in the flame zone through incomplete combustion. This group contains some potentially carcinogenic compounds, such as benzo(a)pyrene.

Emission factors and their ratings for wood combustion in residential wood stoves are presented in Table 1.10-1.

As mentioned, particulate emissions are defined as the total emissions equivalent to that collected by EPA Method 5H (Oregon Method 7). This method employs a heated filter followed by three impingers, an unheated filter, and a final impinger. Particulate emissions data used to develop the factors in Table 1.10-1 are primarily from data collected during field testing programs, and they are presented as values equivalent to that collected with Method 5H.⁸ Conversions are employed, as appropriate, for data collected with other methods. See Reference 2 for detailed discussions of EPA Methods 5H and 28. Other emission factors shown in Table 1.10-1 have been developed from data collected during laboratory testing programs.

References for Section 1.10

1. Standards Of Performance For New Stationary Sources: New Residential Wood Heaters, 53 FR 5860, February 26, 1988.
2. G. E. Weant, Emission Factor Documentation For AP-42 Section 1.10. Residential Wood Stoves, EPA-450/4-89-007, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1989.
3. R. Gay and J. Shah, Technical Support Document For Residential Wood Combustion, EPA-450/4-85-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1986.
4. Residential Wood Heater Test Report, Phase 1, Tennessee Valley Authority, Chattanooga, TN, November 1982.
5. J. A. Rau and J. J. Huntzicker, "Composition And Size Distribution Of Residential Wood Smoke Aerosols". Presented at the 21st Annual Meeting of the Air And Waste Management Association, Pacific Northwest International Section, Portland, OR, November 1984.

6. R. C. McGrillis and R. G. Merrill, "Emission Control Effectiveness Of A Woodstove Catalyst And Emission Measurement Methods Comparison". Presented at the 78th Annual Meeting of the Air And Waste Management Association, Detroit, MI, 1985.
7. L. E. Cottone and E. Messer, Test Method Evaluations And Emissions Testing For Rating Wood Stoves, EPA-600/2-86-100, U. S. Environmental Protection Agency, Cincinnati, OH, October 1986.
8. In-situ Emission Factors For Residential Wood Combustion Units, EPA-450/3-88-013, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1988.
9. K. E. Leese and S. M. Harkins, Effects Of Burn Rate, Wood Species, Moisture Content, And Weight Of Wood Loaded On Woodstove Emissions, EPA-600/2-89-025, U. S. Environmental Protection Agency, Cincinnati, OH, May 1989.
10. Residential Wood Heater Test Report, Phase II, Vol. 1, Tennessee Valley Authority, Chattanooga, TN, August 1983.
11. J. M. Allen, et al., Study Of The Effectiveness Of A Catalytic Combustion Device On A Wood Burning Appliance, EPA-600/7-84-04, U. S. Environmental Protection Agency, Cincinnati, OH, March 1984.
12. J. M. Allen and W. M. Cooke, Control Of Emissions From Residential Wood Burning By Combustion Modification, EPA-600/7-81-091, U. S. Environmental Protection Agency, Cincinnati, OH, May 1981.
13. R. S. Truesdale and J. G. Cleland, "Residential Stove Emissions From Coal And Other Fuels Combustion". Presented at the Specialty Conference on Residential Wood and Coal Combustion, Louisville, KY, March 1982.
14. R. E. Imhoff, et al., "Final Report On A Study Of The Ambient Impact Of Residential Wood Combustion in Petersville, Alabama". Presented at the Specialty Conference on Residential Wood and Coal Combustion, Louisville, KY, March 1982.
15. D. G. Deangelis, et al., Preliminary Characterization Of Emissions From Wood-fired Residential Combustion Equipment, EPA-600/7-80-040, U. S. Environmental Protection Agency, Cincinnati, OH, March 1980.



2.1 REFUSE COMBUSTION

Refuse combustion is generally the burning of predominantly nonhazardous garbage or other solid wastes. Types of combustion devices used to burn refuse include single chamber units, multiple chamber units, trench incinerators, controlled air incinerators, and pathological incinerators. These devices are used to burn municipal, commercial, industrial, pathological, and domestic refuse.

2.1.1 Municipal Waste Combustion

There are currently over 150 municipal waste combustion (MWC) plants in operation in the United States.¹ Three main types of combustors are used: mass burn, modular, and refuse derived fuel (RDF) fired. In mass burn units, the municipal solid waste (MSW) is combusted without any preprocessing other than removal of items too large to go through the feed system. In a typical mass burn combustor, refuse is placed on a grate that moves through the combustor. Combustion air in excess of stoichiometric amounts is supplied both below (underfire air) and above (overfire air) the grate. Mass burn combustors are usually erected at the site (as opposed to being prefabricated at another location) and range in size from 46 to 900 megagrams (50 to 1000 tons) per day of refuse throughput per unit. Many mass burn facilities have two or more combustors and have combined site capacities of greater than 900 megagrams (1000 tons) per day. The mass burn category can be further divided into waterwall and refractory wall designs. Most refractory wall combustors were built prior to the early 1970s. Newer units are mainly waterwall designs, which have water-filled tubes in the walls of the combustor used to recover heat for production of steam and/or electricity. Process diagrams for one type of refractory wall combustor and a typical waterwall combustor are presented in Figures 2.1.1-1 and 2.1.1-2, respectively.

Modular combustors also burn waste without preprocessing, but they are typically shop fabricated and generally range in size from 5 to 110 megagrams (5 to 120 tons) per day of refuse throughput. One of the most common types of modular combustors is the starved air or controlled air type, incorporating two combustion chambers. A process diagram of a typical modular starved-air combustor is presented in Figure 2.1.1-3. Air is supplied to the primary chamber at substoichiometric levels. The incomplete combustion products (carbon monoxide and organic compounds) pass into the secondary combustion chamber where excess air is added and combustion is completed. Another type of modular combustor, functionally similar to mass burn units, uses excess air in the primary chamber.

Refuse derived fuel fired combustors burn processed waste which may vary from shredded waste to finely divided fuel suitable for co-firing with pulverized coal. A process diagram for a typical RDF combustor is shown in Figure 2.1.1-4. Preprocessing usually consists of removing noncombustibles and shredding the waste, which raises the heating value and provides a more

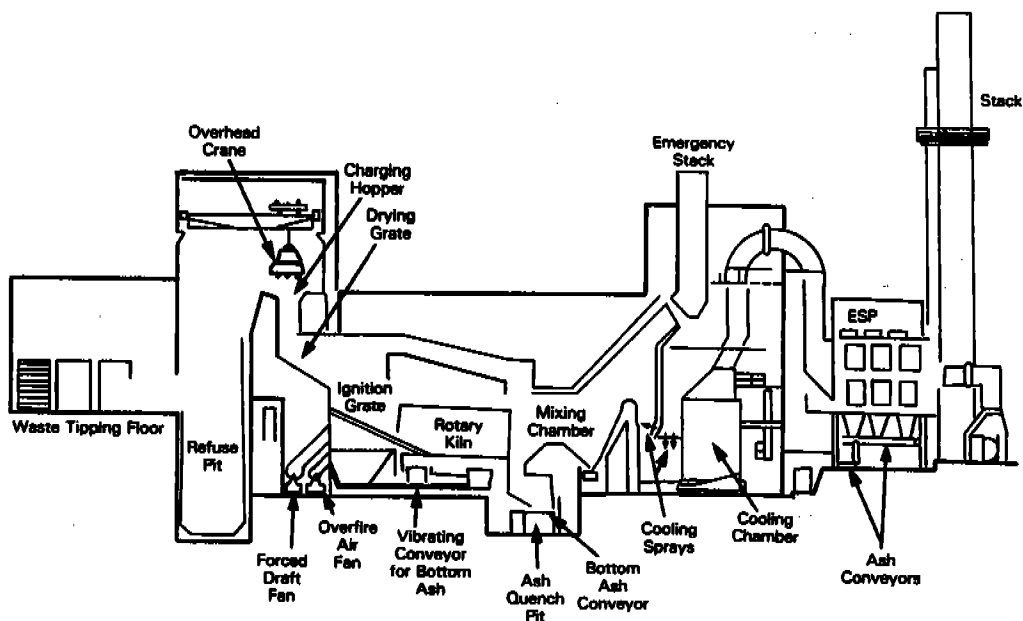


Figure 2.1-1. Mass burn refractory wall combustor with grate/rotary kiln.

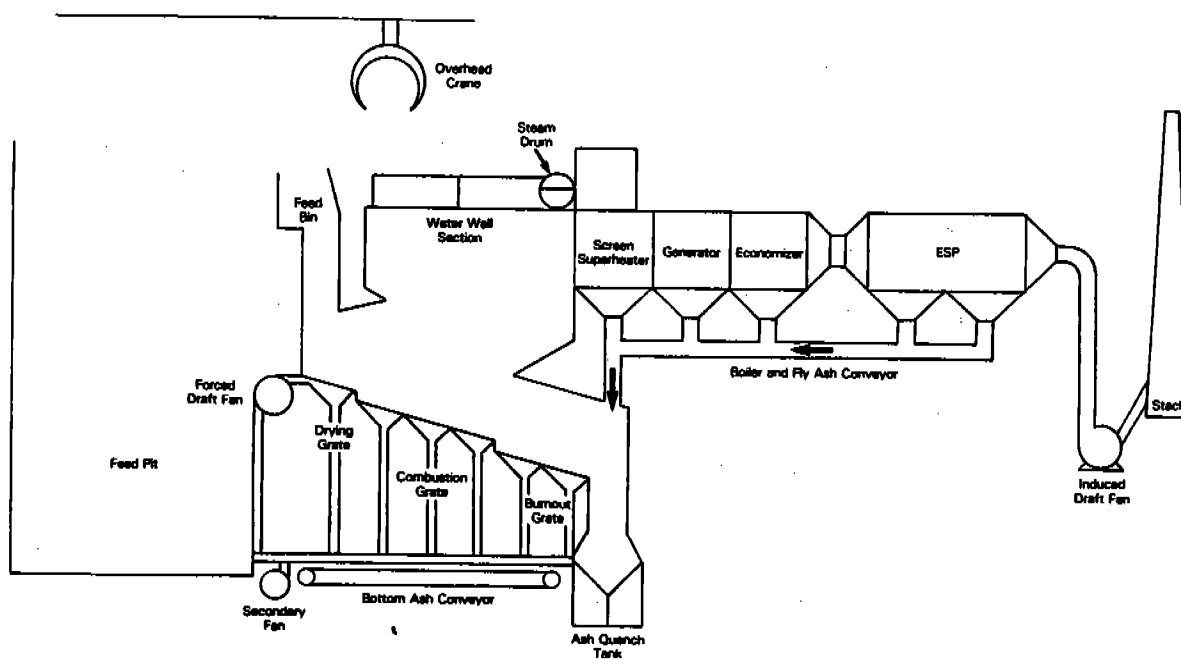


Figure 2.1-2. Mass burn waterwall combustor.

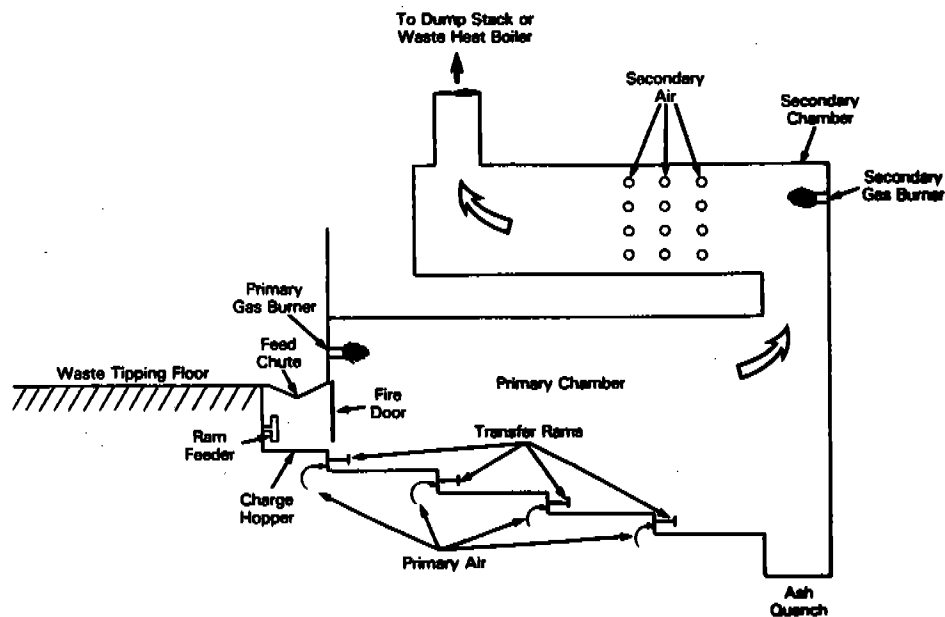


Figure 2.1-3. Modular starved-air combustor with transfer rams.

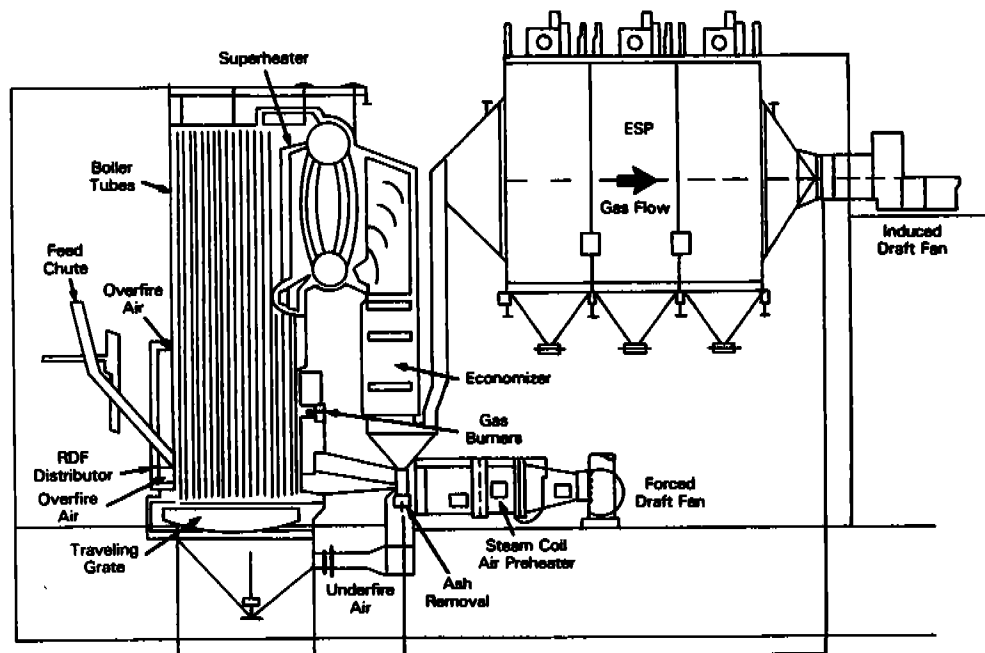


Figure 2.1-4. RDF fired spreader stoker boiler.

uniform fuel. Combustor sizes range from 290 to 1,300 megagrams (320 to 1400 tons) per day. Most RDF facilities have two or more combustors, and site capacities range up to 2700 megagrams (3000 tons) per day. RDF facilities typically recover heat for production of steam and/or electricity.

There are also small numbers of other types of MWCs. One type used less extensively is the rotary waterwall combustor. As with mass burn units, rotary waterwall combustors burn waste without preprocessing but differ in design from most mass burn units in the use of a rotary combustion chamber equipped with water-filled tubes for heat recovery. Other types of MWCs include batch incinerators and fluidized bed combustors.

Over 30 percent of the units currently operating are mass burn units (including refractory and waterwall) and another 40 to 50 percent are modular units. Over 10 percent of the units are RDF units and the remainder of the units are of other designs. In terms of waste combusted, mass burn units account for about 60 percent of the MSW combusted, modular units account for 8 percent, and RDF units for 30 percent.¹

2.1.1.1 Process Description

Types of combustors described in this section include:

- Mass burn refractory wall
- Mass burn waterwall
- Refuse derived fuel fired
- Modular starved air
- Modular excess air
- Rotary waterwall
- Fluidized bed

Mass Burn Refractory Wall - At least three distinct combustor designs make up the existing population of refractory wall combustors. The first design is a batch fed upright combustor, where the combustor may be cylindrical or rectangular in shape. This type of combustor was prevalent in the 1950s, but no additional units of this design are expected to be built.

A more common design consists of rectangular combustion chambers with traveling, rocking, or reciprocating grates. This type of combustor is continuously fed and operates in an excess air mode with both underfire and overfire air provided. The primary distinction between plants with this design is the manner in which the waste is moved through the combustor. The traveling grate moves on a set of sprockets and does not agitate the waste bed as it advances through the combustor. Rocking and reciprocating grate systems agitate and aerate the waste bed as it advances through the combustion chamber. The system generally discharges the ash at the end of the grates to a water quench pit for collection and disposal in a landfill.

A third major design type in the mass burn refractory wall population is a system which combines grate burning technology with a rotary kiln. Two grate sections (drying and ignition) precede a refractory lined rotary kiln. Combustion is completed in the kiln, and ash leaving the kiln falls into a water quench. This system is depicted in Figure 2.1.1-1.

Most mass burn refractory wall combustors have electrostatic precipitators (ESPs) for particulate control. Others have a wet particulate control device, such as a wet scrubber.

Mass Burn Waterwall - With this type of system, unprocessed waste with large, bulky, noncombustibles removed is delivered by an overhead crane to a feed hopper from which it is fed into the combustion chamber. Earlier mass burn designs utilized gravity feeders, but it is more typical today to feed by means of single or dual hydraulic rams that operate on a set frequency.

Nearly all modern conventional mass burn facilities utilize reciprocating grates to move the waste through the combustion chamber. The grates typically include two or three separate sections where designated stages in the combustion process occur. The initial grate section is referred to as the drying grate, where heat reduces the moisture content of the waste prior to ignition. The second grate section is the burning grate, where the majority of active burning takes place. The third grate section is referred to as the burnout or finishing grate, where remaining combustibles are burned. Smaller units may have two rather than three individual grate sections. Bottom ash is discharged from the finishing grate into a water filled ash quench pit. Dry ash systems have been used in some designs, but are not widespread.

Combustion air is added to the waste from beneath the grate by way of underfire air plenums. The majority of mass burn waterwall systems supply underfire air to the individual grate sections through multiple plenums. As the waste bed burns, additional air is required to oxidize fuel rich gases and complete the combustion process. Overfire air is injected through rows of high pressure nozzles (usually two to three inches in diameter). Typically, mass burn waterwall MWCs are operated with 80 to 100 percent excess air.

The majority of mass burn waterwall combustors have ESPs for particulate control. Several plants have acid gas controls in combination with a fabric filter or ESP.

Refuse Derived Fuel - As a means of raising the heating value, raw MSW can be processed to refuse derived fuel (RDF) before combustion. A set of standards for classifying RDF types has been established by the American Society For Testing And Materials.² The type of RDF used is dependent on the boiler design. Boilers that are designed to burn RDF as a primary fuel usually utilize spreader stokers and fire RDF-3 (fluff, or f-RDF) in a semi-suspension mode. This mode of feeding is accomplished by using an air swept distributor, which allows a portion of the feed to burn in suspension and the remainder to be burned out after falling on a horizontal traveling grate.

Suspension fired RDF boilers, such as pulverized coal (PC) fired boilers, can co-fire RDF-3 or RDF-4 (powdered or p-RDF). If RDF-3 is used, the fuel processing must be more extensive so that a very fine fluff results. Currently, PC boilers co-fire fluff with pulverized coal. Suspension firing is usually associated with larger boilers due to the increased boiler height and retention time required for combustion to be completed in total suspension. Smaller systems firing RDF in suspension require moving or dump grates in the lower furnace to handle the falling material that is not completely combusted in suspension. Boilers co-firing RDF in suspension are generally limited to 50 percent RDF, based on heating value.³

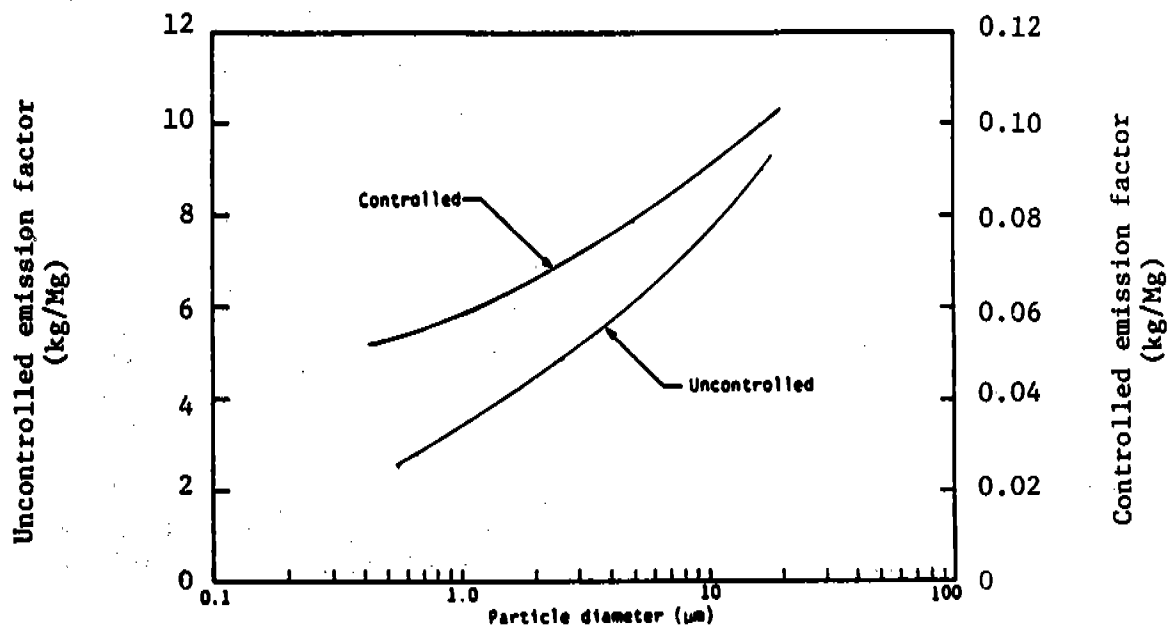


Figure 2.1-5. Cumulative particle size distribution and size specific emission factors for mass burn combustors.

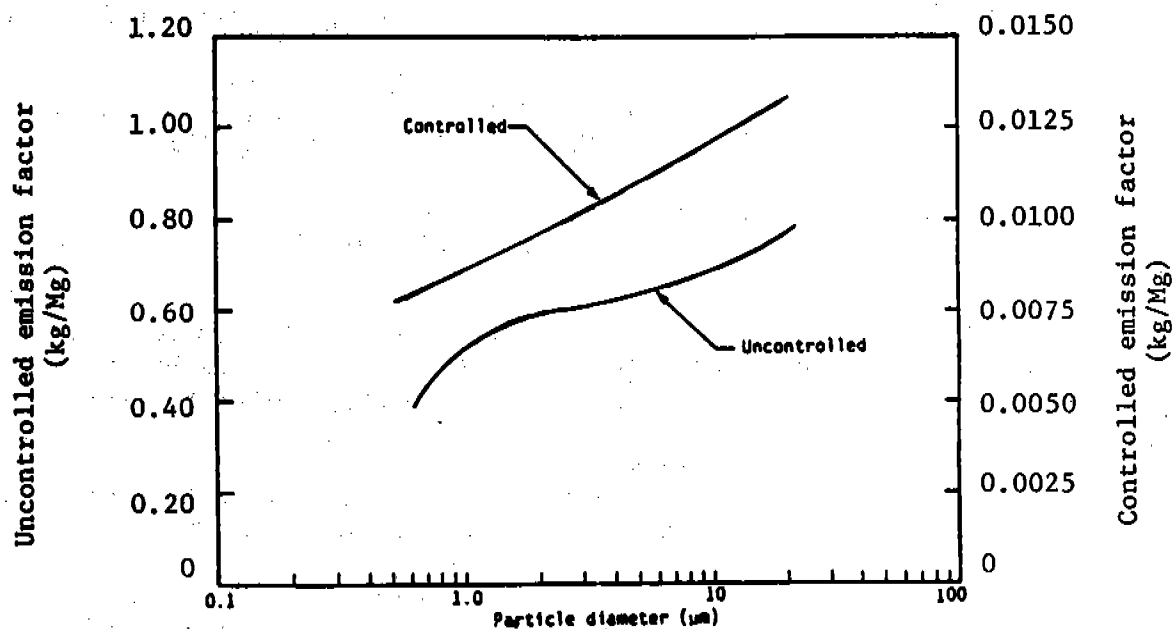


Figure 2.1-6. Cumulative particle size distribution and size specific emission factors for starved air combustors.

TABLE 2.1-1. EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTION^a

Pollutant	Particle diameter (µg)	Mass Burn			Starved Air			Refuse-Derived Fuel		
		Uncontrolled kg/Mg (lb/ton)	Controlled kg/Mg (lb/ton)	Emission Factor Rating	Uncontrolled kg/Mg (lb/ton)	Controlled kg/Mg (lb/ton)	Emission Factor Rating	Uncontrolled kg/Mg (lb/ton)	Controlled kg/Mg (lb/ton)	Emission Factor Rating
PM ₁₀	0.625	2.7 (5.4)	0.055 (0.11) ^b	C	0.40 (0.80)	0.0080 (0.016) ^b	D	4.4 (8.8)	0.090 (0.18) ^c	E
	1.0	3.5 (7.0)	0.065 (0.13)		0.50 (1.0)	0.0095 (0.019)		10 (20)	0.19 (0.38)	
	2.5	4.6 (9.2)	0.075 (0.15)		0.60 (1.2)	0.010 (0.020)		16 (32)	0.29 (0.58)	
	5.0	6.0 (12)	0.080 (0.16)		0.65 (1.3)	0.011 (0.022)		21 (42)	0.36 (0.72)	
	10.0	7.0 (14)	0.090 (0.18)		0.70 (1.4)	0.012 (0.024)		22 (44)	0.37 (0.74)	
	15.0	9.0 (18)	0.10 (0.20)		0.75 (1.5)	0.013 (0.026)		24 (48)	0.39 (0.78)	
Total particulate		19 (38)	0.19 (0.38) ^b	C	0.95 (1.9)	0.015 (0.030) ^b	D	40 (80)	0.04 (0.08) ^c	D
Lead		0.09 (0.18)	0.011 (0.022) ^b	C	0.06 (0.12)	0.001 (0.002) ^b	D	0.065 (0.13)	0.014 (0.028) ^c	D
Sulfur dioxide		0.85 (1.7)	0.55 (1.1) ^e	D	0.85 (1.7)	0.55 (1.1) ^e	D	0.85 (1.7)	0.55 (1.1) ^e	D
Nitrogen oxides		1.8 (3.6)	1.8 (3.6) ^c	D	2.2 (4.4)	2.2 (4.4) ^c	D	2.5 (5.0)	2.5 (5.0) ^c	D
Carbon monoxide		1.1 (2.2)	1.1 (2.2) ^e	D	0.17 (3.4)	0.17 (3.4) ^c	D	1.8 (3.6)	1.8 (3.6) ^b	D
Volatile organic compounds										
Methane		0.0032 (0.0064)	0.0032 (0.0064) ^b	D	NA	NA		NA	NA	
Nonmethane		0.05 (0.10)	0.05 (0.10) ^b	D	NA	NA		NA	NA	

^aReference 7.^bControl devices include ESP and FF.^cControl device is an ESP.^dAverage for all three combustor types.^eControl devices include ESP, FF, dry scrubbers, and wet scrubbers.

The emission controls for RDF systems are typically ESPs alone, although acid gas controls are used with particulate control devices in some systems.

Modular Starved Air - The basic design of a modular starved air combustor consists of two separate combustion chambers, "primary" and "secondary". Waste is batch fed to the primary chamber by a hydraulically activated ram. The charging bin is filled by a front end loader. Waste is fed automatically on a set frequency, generally 6 to 10 minutes between charges.

Waste is moved through the primary combustion chamber by either hydraulic transfer rams or reciprocating grates. Combustors using transfer rams have individual hearths upon which combustion takes place. Grate systems generally include two separate grate sections. In either case, waste retention times in the primary chamber are long, up to 12 hours. Bottom ash is usually discharged to a wet quench pit.

The quantity of air introduced in the primary chamber defines the rate at which waste burns. The primary chamber essentially functions as a gasifier, producing a hot fuel gas which is burned out in the secondary chamber. The combustion air flow rate to the primary chamber is controlled to maintain an exhaust gas temperature set point (generally 650 to 760°C [1200 to 1400°F]), which normally corresponds to about 40 percent theoretical air. Other system designs operate with a primary chamber temperature between 870 to 980°C (1600 and 1800°F), which requires 50 to 60 percent theoretical air.

As the hot, fuel rich flue gases flow to the secondary chamber, they are mixed with excess air to complete the burning process. The temperature of the exhaust gases from the primary chamber is above the autoignition point. Thus, completing combustion is simply a matter of introducing air to the fuel rich gases. The amount of air added to the secondary chamber is controlled to maintain a desired flue gas exit temperature, typically 980 to 1200°C (1800 to 2200°F). Approximately 80 percent of the total combustion air is introduced as secondary air, so that excess air levels for the system are about 100 percent. Typical operating ranges vary from 80 to 150 percent excess air.

The walls of both combustion chambers are refractory lined. Early starved air modular combustors did not include heat recovery, but a waste heat boiler is common in newer installations, with two or more combustion modules manifolded to a boiler. Combustors with heat recovery capabilities also have dump stacks. A dump stack is an alternate emission point, located upstream of the boiler and/or air pollution control equipment. It is for use in an emergency, or when the boiler and/or air pollution control equipment are not in operation.

Because emissions are relatively low, many modular starved air MWCs do not have emissions control. Those that do usually have ESPs for particulate control, although fabric filters have been used. A few newer starved air MWCs have acid gas controls.

Modular Excess Air - This design is similar to that of modular starved air units. The basic design includes two separate combustion chambers (referred to as the "primary" and "secondary" chambers). Waste is batch fed to the primary chamber, which is refractory lined. The waste is moved through

TABLE 2.1-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR MUNICIPAL WASTE COMBUSTORS^a

Particle Size (ug)	Cumulative mass % < stated size						Cumulative emission factor, kg/Mg (lb/ton)					
	Uncontrolled			Controlled			Uncontrolled			Controlled		
	MB	SA	RDF	MB	SA	RDF	MB	SA	RDF	MB	SA	RDF
15.0	47	79	60	53	87	71	9.0 (18)	0.75 (1.5)	24 (48)	0.10 (0.20)	0.013 (0.026)	0.39 (0.7)
10.0	37	74	55	47	80	67	7.0 (14)	0.70 (1.4)	22 (44)	0.090 (0.18)	0.012 (0.024)	0.37 (0.7)
5.0	32	68	53	42	73	65	6.0 (12)	0.65 (1.3)	21 (42)	0.080 (0.16)	0.011 (0.022)	0.36 (0.7)
2.5	24	63	40	39	67	53	4.6 (9.2)	0.60 (1.2)	16 (32)	0.075 (0.15)	0.010 (0.020)	0.29 (0.5)
1.0	18	53	25	34	63	35	3.5 (7.0)	0.50 (1.0)	10 (20)	0.065 (0.13)	0.0095 (0.019)	0.19 (0.3)
0.625	14	42	11	29	53	16	2.7 (5.4)	0.40 (0.80)	4.4 (8.8)	0.055 (0.11)	0.0080 (0.016)	0.09 (0.1)
Total	100	100	100	100	100	100	19 (38)	0.95 (1.9)	40 (80)	0.19 (0.38)	0.015 (0.030)	0.55 (1.1)

^aReference 3. MB = mass burn. SA = starved air. DF = refuse-derived fuel.

TABLE 2.1-3. UNCONTROLLED EMISSION FACTORS FOR INDUSTRIAL/COMMERCIAL REFUSE COMBUSTORS^a

EMISSION FACTOR RATING: A

Incinerator type	Particulate		Sulfur oxides ^b		Carbon monoxide		Volatile organics ^c		Nitrogen oxides ^d	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Multiple chambers ^e Single chambers ^g	3.5	7	1.25	2.5 ^f	5	10	1.5	3	1.5	3
	7.5	15	1.25	2.5 ^f	10	20	7.5	15	1	2
Trench ^h Wood Rubber tires Municipal refuse	6.5	13	0.05	0.1 ^j	NA	NA	NA	NA	2	4
	69	138	NA	NA	NA	NA	NA	NA	NA	NA
	18.5	37	1.25	2.5 ^f	NA	NA	NA	NA	NA	NA
Flue fed Single chamber ^k Modified ^m	15	30	0.25	0.5	10	20	7.5	15	1.5	3
	3	6	0.25	0.5	5	10	1.5	3	5	10
Domestic single chamber Without primary burner ⁿ With primary burner ^p	17.5	35	0.25	0.5	150	300	50	100	0.5	1
	3.5	7	0.25	0.5	Neg	Neg	1	2	1	2
	4	8	Neg	Neg	Neg	Neg	Neg	Neg	1.5	3
Pathological ^q										

^aFactors are averages based on EPA procedures for incinerator stack testing. NA = not available. Neg = negligible.^bExpressed as SO₂.^cExpressed as methane.^dExpressed as NO₂.^eReferences 6,10-13.^fBased on municipal incinerator data.^gReferences 6,10-11,13.^hReference 8.ⁱBased on data for wood combustion in conical burners.^kReferences 6,11-15.^mWith afterburners and draft controls. References 6,13-14.ⁿReferences 10-11.^pReference 10.^qReference 6,16.

the primary chamber by hydraulic transfer rams, oscillating grates or a revolving hearth. Bottom ash is discharged to a wet quench pit.

The majority of combustion air is provided in the primary chamber. Up to 200 percent excess air can be supplied. Flue gas burnout occurs in the secondary chamber, which is also refractory lined. Heat is recovered in waste heat boilers.

Particulate emissions are typically controlled by ESPs, although other controls including a cyclone and an electrified gravel bed, are used. A few newer facilities have acid gas controls. Some modular excess air combustors operate without emission controls.

Rotary Waterwall - This type of system uses a rotary combustion chamber with pre-sorting of objects too large to fit in the combustor. The waste is ram fed to the rotary combustion chamber, which sits at an angle and rotates slowly, causing the waste to advance and tumble as it burns. Bottom ash is discharged from the rotary combustor to a stationary after burning grate and then into a wet quench pit.

Underfire air is injected through the waste bed and overfire air is provided directly above the waste bed. Approximately 80 percent of the combustion air is provided along the combustion chamber length with most of this provided in the first half of the length. The rest of the combustion air is supplied to the afterburner grate and above the rotary combustor outlet in the boiler chamber. Water flowing through the tubes in the rotary chamber recovers heat from combustion. Additional heat recovery occurs in the boiler waterwall, superheater and economizer. Flue gas emissions are controlled by ESPs or fabric filters.

Fluidized Bed - This technology is an alternative method of combusting RDF. Fluffed or pelletized RDF is combusted on a turbulent bed of heated noncombustible material such as limestone, sand, silica, or alumina. The bed is suspended or "fluidized" through introduction of underfire air at a high flow rate. Overfire air is used to complete combustion.

There are two basic types of fluidized bed combustion systems; bubbling bed combustors and circulating fluidized bed combustors. With bubbling bed combustors, most of the fluidized solids are maintained near the bottom of the combustor by using relatively low air fluidization velocities. This helps prevent the entrainment of solids from the bed into the flue gas, minimizing recirculation or reinjection of bed particles. Circulating fluidized bed combustors operate at relatively high fluidization velocities to promote carry over of solids into the upper section of the combustor. Combustion occurs in both the bed and upper section of the combustor. By design, a fraction of the bed material is entrained in the combustion gas and enters a cyclone separator which recycles unburned waste and inert particles to the lower bed.

2.1.1.2 Emissions And Controls

Refuse combustors have the potential to emit significant quantities of pollutants to the atmosphere. The major pollutants emitted are: (1) particulate matter, (2) metals (in solid form on particulate, except for mercury), (3) acid gases (primarily hydrogen chloride [HCl] and sulfur dioxide [SO₂]), (4) carbon monoxide (CO), (5) nitrogen oxides (NO_x), and (6) toxic

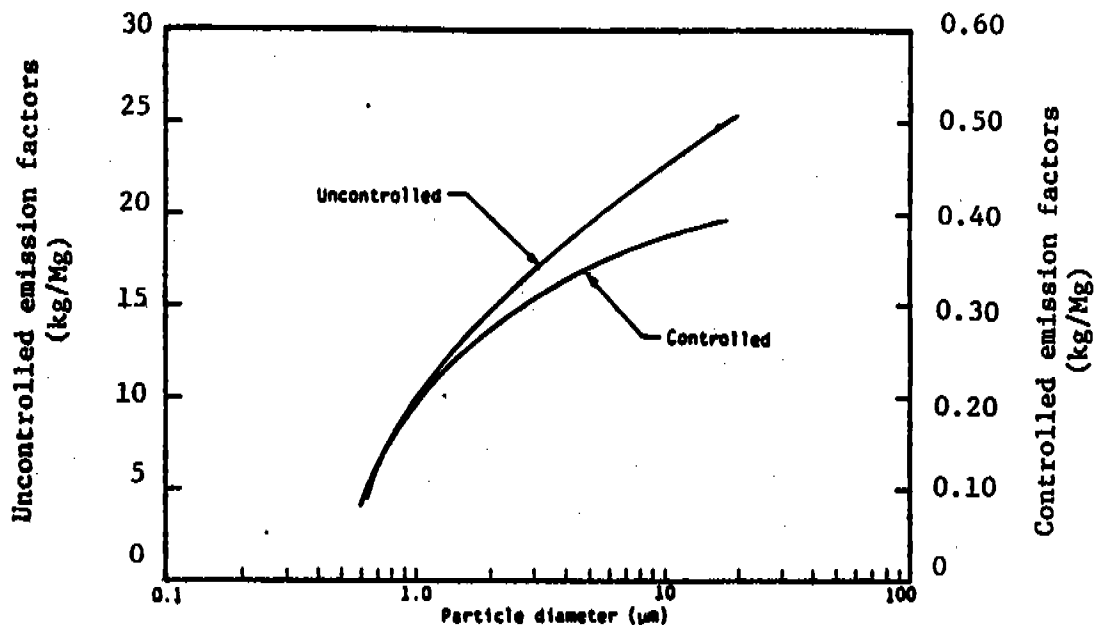


Figure 2.1-7. Cumulative particle size distribution and size specific emission factors for refuse-derived fuel combustors.

organic compounds (most notably chlorinated dibenzo-p-dioxins and chlorinated dibenzo furans [CDD/CDF]).

Particulate matter is emitted because of the turbulent movement of the combustion gases with respect to the burning refuse and resultant ash. Particulate matter is also produced when metals that are volatilized in the combustion zone condense in the exhaust gas stream. The particle size distribution and concentration of the particulate emissions leaving the combustor vary widely, depending on the composition of the refuse being burned and the type and operation of the combustor.

Particulate matter from MWCs contributes to hazardous air emissions in two ways. First, trace metals are emitted because they are typically concentrated in the smaller size fraction of the total particulate emissions where capture is more difficult. Secondly, the amount of particulate surface area may contribute to the availability of sites for catalytic reactions involving toxic organic compounds, thus playing a role in potential downstream formation mechanisms (see below).

Metals emissions are affected by two primary factors, (1) level of particulate matter control, and (2) flue gas temperature. Most metals (with the exception of mercury) are associated with fine particulate, and would therefore be removed as the fine particulate are removed. Mercury is generally not contained on particulate matter and removal is not a function of particulate removal.

Concentrations of HCl and SO₂ in MWC flue gases are directly related to the quantities of chlorine and sulfur in the waste. Refuse components that are major contributors of sulfur include rubber, plastics, foodwastes,

yardwastes, and paper. Similarly, plastics and miscellaneous organic compounds are the major sources of chlorine in refuse. Therefore, chlorine and sulfur contents can vary considerably based on seasonal and local waste variations.⁴

Carbon monoxide can be formed when insufficient oxygen is available for complete combustion, or when excess air levels are too high, thus lowering combustion temperature.

Nitrogen oxides are formed during combustion through (1) oxidation of nitrogen in the waste and (2) fixation of atmospheric nitrogen. Conversion of nitrogen in the waste occurs at relatively low temperatures (less than 1090°C [2000°F]), while fixation of atmospheric of atmospheric nitrogen occurs at higher temperatures. 75 to 80 percent of NO_x formed is associated with nitrogen in the waste.⁵

CDD/CDF may be formed through two mechanisms. In the first, CDD/CDF are formed as products of reactions in the furnace when the combustion process fails to completely convert hydrocarbons to carbon dioxide and water. Alternatively, organic compounds which escape the high temperature regions of the furnace may react at lower temperatures downstream to form CDD/CDF. Formation of CDD/CDF across the ESP is a recently identified concern with the operation of MWC ESPs at temperatures above roughly 230°C (450°F). The mechanism and extent of formation are poorly understood.⁶

A wide variety of control technologies are used to control emissions from MWCs. For particulate control, electrostatic precipitators are most frequently used; although other particulate control devices (including electrified gravel beds, fabric filters, cyclones and venturi scrubbers) are used. Processes used for acid gas control include wet scrubbing, dry sorbent injection, and spray drying.

Electrostatic Precipitator - Particulate emissions from MWCs are most often controlled using ESPs. In this process, flue gas flows between a series of high voltage (20 to 100 kilovolts) discharge electrodes and grounded metal plates. Negatively charged ions formed by this high voltage field (known as a "corona") attach to PM in the flue gas, causing the charged particles to migrate toward the grounded plates. Once the charged particles are collected on the grounded plates, the resulting dust layer is removed from the plates by rapping, washing, or some other method and collected in a hopper. When the dust layer is removed, some of the collected PM becomes reentrained in the flue gas. To assure good PM collection efficiency during plate cleaning and electrical upsets, ESPs have several fields located in series along the direction of flue gas flow that can be energized and cleaned independently. Particles reentrained when the dust layer is removed from one field can be recollected in a downstream field.

Small particles generally have lower migration velocities than large particles, and are therefore more difficult to collect. This factor is especially important to MWCs because of the large amount of total fly ash smaller than one micron. As compared to pulverized coal fired combustors, in which only 1 to 3 percent of the fly ash is generally smaller than 1 micron, 20 to 70 percent of the fly ash at the ESP inlet for MWCs is reported to be smaller than 1 micron. As a result, effective collection of PM from MWCs

requires greater collection areas and lower flue gas velocities than many other combustion types.

The most common types of ESPs used by MWCs are (1) plate wire units in which the discharge electrode is a bottom weighted or rigid wire and (2) flat plate units which use flat plates rather than wires as the discharge electrode. Plate wire ESPs generally are better suited for use with fly ashes with large amounts of small particulate and with large flue gas flow rates (greater than 5700 actual cubic meters per minute [200,000 actual cubic feet per minute]). Flat plate units are less sensitive to back corona problems and are thus well suited for use with high resistivity PM. Both of these ESP types have been widely used on MWCs in the U. S., Europe, and Japan.

As an approximate indicator of collection efficiency, the specific collection area (SCA) of an ESP is frequently used. The SCA is calculated by dividing the collecting electrode plate area by the actual flue gas flow rate and is expressed as square feet of collecting area per 1000 actual cubic feet per minute of flue gas. In general, the higher the SCA, the higher the collection efficiency.

Fabric Filters - Fabric filters (baghouses) are frequently used in combination with acid gas controls and are of two basic designs, reverse air and pulse cleaned. Both methods provide additional potential for acid gas removal as the filter cake builds up on the bags. In a reverse air fabric filter, flue gas flows through unsupported filter bags, leaving the particulate on the inside of the bags. The particulate builds up to form a particulate filter cake. Once excessive pressure drop across the filter cake is reached, air is blown through the filter in the opposite direction, the filter bag collapses, and the filter cake falls off and is collected. In a pulse cleaned fabric filter, flue gas flows through supported filter bags leaving particulate on the outside of the bags. To remove built up particulate filter cake, compressed air is introduced through the inside of the filter bag, the filter bag expands and the filter cake falls off and is collected. Particulate removal by a fabric filter following acid gas controls is typically greater than 99 percent.

Wet Scrubbers - Many types of wet scrubbers are used for controlling acid emissions from MWCs. These include spray towers, centrifugal scrubbers, and venturi scrubbers. In these devices, the flue gas enters the absorber where it is contacted with enough alkaline solution to saturate the gas stream. The alkaline solution, typically containing calcium hydroxide [$\text{Ca}(\text{OH})_2$] reacts with the acid gas to form salts, which are generally insoluble and may be removed by sequential clarifying, thickening, and vacuum filtering. The dewatered salts or sludges are then landfilled.

Dry Sorbent Injection - This type of technology has been developed primarily to control acid gas emissions. However, when combined with flue gas cooling and either a fabric filter or ESP, sorbent injection processes may also control CDD/CDF and particulate emissions from MWCs. Two primary subsets of dry sorbent injection technologies exist. The more widely used of these approaches, referred to as duct sorbent injection (DSI), involves injecting dry alkali sorbents into flue gas downstream of the combustor outlet and upstream of the particulate control device. The second approach, referred to as furnace sorbent injection (FSI), injects sorbent directly into the combustor.

In DSI, powdered sorbent is pneumatically injected into either a separate reaction vessel or a section of flue gas duct located downstream of the combustor economizer or quench tower. Alkali in the sorbent (generally calcium or sodium) reacts with HCl, hydrogen fluoride (HF), and SO₂ to form alkali salts (e. g., calcium chloride [CaCl₂], calcium fluoride [CaF₂], and calcium sulfite [CaSO₃]). By lowering the acid content of the flue gas, downstream equipment can be operated at reduced temperatures while minimizing the potential for acid corrosion of equipment. Reaction products, fly ash, and unreacted sorbent are collected with either a fabric filter or ESP.

Acid gas removal efficiency with DSI depends on flue gas temperature, sorbent type and feed rate, and the extent of sorbent mixing with the flue gas. Flue gas temperature at the point of sorbent injection can range from 180 to 320°C (350 to 600°F) depending on the sorbent being used and the design of the process. Sorbents that have been successfully tested include hydrated lime (Ca(OH)₂), soda ash (Na₂CO₃), and sodium bicarbonate (NaHCO₃). Based on published data for hydrated lime, DSI can achieve relatively high removals of HCl (60 to 90 percent) and SO₂ (40 to 70 percent) under proper operating conditions. Limestone (CaCO₃) has also been tested but is relatively unreactive at the above temperatures.

By combining flue gas cooling with DSI, it may be possible to increase the potential for CDD/CDF removal which is believed to occur through a combination of vapor condensation and adsorption onto the sorbent surface. Cooling may also benefit PM control by decreasing the effective flue gas flow rate (i. e., actual cubic meters per minute) and reducing the resistivity of individual particles.

Furnace sorbent injection involves the injection of powdered alkali sorbent into the furnace section of a combustor. This can be accomplished by addition of sorbent to the overfire air, injection through separate ports, or mixing with the waste prior to feeding to the combustor. As with DSI, reaction products, flyash, and unreacted sorbent are collected using a fabric filter or ESP.

The basic chemistry of FSI is similar to DSI. Both use a reaction of sorbent with acid gases to form alkali salts. However, several key differences exist in these two approaches. First, by injecting sorbent directly into the furnace (at temperatures of 870 to 1200°C [1600 to 2200°F]) limestone can be calcined in the combustor to more reactive lime, thereby allowing use of less expensive limestone as a sorbent. Second, at these temperatures, SO₂ and lime react in the combustor, thus providing a mechanism for effective removal of SO₂ at relatively low sorbent feed rates. Third, by injecting sorbent into the furnace rather than into a downstream duct, additional time is available for mixing and reaction between the sorbent and acid gases. As a result, it may be possible to remove HCl and SO₂ from the flue gas at lower sorbent-to-acid gas stoichiometric ratios than with DSI. Fourth, if a significant portion of the HCl is removed before the flue gas exits the combustor, it may be possible to reduce the formation of CDD/CDF in latter sections of the flue gas ducting. However, HCl and lime do not react with each other at temperatures above 760°C (1,400°F).

Spray Drying - Spray drying is designed to control SO₂ and HCl emissions. When used in combination with particulate control, the system can control CDD/CDF, PM, SO₂, and HCl emissions from MWCs. In the spray drying process,

lime slurry is injected into a spray dryer (SD). The water in the slurry evaporates to cool the flue gas and the lime reacts with acid gases to form salts that can be removed by a PM control device. The simultaneous evaporation and reaction increases the moisture and particulate content in the flue gas. The particulate leaving the SD contains fly ash plus calcium salts, water, and unreacted lime.

The key design and operating parameters that significantly affect SD performance are SD outlet temperature and lime-to-acid gas stoichiometric ratio. The SD outlet temperature is controlled by the amount of water in the slurry. More effective acid gas removal occurs at lower temperatures, but the temperature must be high enough to ensure the slurry and reaction products are adequately dried prior to collection in the PM control device. For MWC flue gas containing significant chlorine, a minimum SD outlet temperature of around 120°C (240°F) is required to control agglomeration of PM and sorbent by calcium chloride. The stoichiometric ratio is the molar ratio of calcium fed to the theoretical amount of calcium required to react with the inlet HCl and SO₂. Lime is fed in quantities sufficient to react with the peak acid gas concentrations expected without severely decreasing performance. The lime content in the slurry must be maintained at or below approximately 30 percent by weight to prevent clogging of the lime slurry feed system and spray nozzles.

Spray drying can be used in combination with either a fabric filter or an ESP for PM control. Both combinations have been used for MWCs in the United States, although SD/fabric filter systems are more common. Typical removal efficiencies range from 50 to 90 percent for SO₂ and for 70 to 95 percent for HCl.

Emission factors for municipal waste combustors are shown in Table 2.1-1. Table 2.1-2 shows the cumulative particle size distribution and size specific emission factors for municipal waste combustors. Figures 2.1-5, 2.1-6 and 2.1-7 show the cumulative particle size distribution and size specific emission factors for mass burn, starved air and RDF combustors, respectively.

2.1.2 Other Types Of Combustors⁸⁻¹¹

The most common types of combustors consist of a refractory-lined chamber with a grate upon which refuse is burned. In some newer incinerators water-walled furnaces are used. Combustion products are formed by heating and burning of refuse on the grate. In most cases, since insufficient underfire (undergrate) air is provided to enable complete combustion, additional over-fire air is admitted above the burning waste to promote complete gas-phase combustion. In multiple-chamber incinerators, gases from the primary chamber flow to a small secondary-mixing chamber where more air is admitted, and more complete oxidation occurs. As much as 300 percent excess air may be supplied in order to promote oxidation of combustibles. Auxilliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small-size incinerators are single-chamber units in which gases are vented from the primary combustion chamber directly into the exhaust stack. Single-chamber incinerators of this type do not meet modern air pollution codes.

2.1.2.1 Process Description⁸⁻¹¹

Industrial/commercial Combustors - The capacities of these units cover a wide range, generally between 22.7 and 1800 kilograms (50 and 4000 pounds) per hour. Of either single- or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial combustors are similar to municipal combustors in size and design. Better designed emission control systems include gas-fired afterburners, scrubbers, or both.

Trench Combustors - A trench combustor is designed for the combustion of wastes having relatively high heat content and low ash content. The design of the unit is simple. A U-shaped combustion chamber is formed by the sides and bottom of the pit, and air is supplied from nozzles (or fans) along the top of the pit. The nozzles are directed at an angle below the horizontal to provide a curtain of air across the top of the pit and to provide air for combustion in the pit. Low construction and operating costs have resulted in the use of this combustor to dispose of materials other than those for which it was originally designed. Emission factors for trench combustors used to burn three such materials are included in Table 2.1-4.¹²

Domestic Combustors - This category includes combustors marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

Flue-fed Combustors - These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the combustor flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.

Pathological Combustors - These are combustors used to dispose of animal remains and other organic material of high moisture content. Generally, these units are in a size range of 22.7 to 45.4 kilograms (50 to 100 pounds) per hour. Wastes are burned on a hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and minimal emissions.

2.1.2.2 Emissions And Controls⁸

Operating conditions, refuse composition, and basic combustor design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has a significant effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side, or from the top of the combustion chamber. As underfire air is increased, an increase in fly-ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and a subsequent release of large quantities of particulates. Large quantities of uncombusted particulate matter and carbon monoxide are also emitted for an extended period after charging of batch-fed units because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions are strongly dependent upon grate type. The use of a rotary kiln and reciprocating grates results in higher particulate emissions than the use of a rocking or traveling grate. Emissions of oxides of sulfur are

TABLE 2.1-4. UNCONTROLLED EMISSION FACTORS FOR REFUSE COMBUSTORS OTHER THAN MUNICIPAL WASTE^a

EMISSION FACTOR RATING: A

Incinerator type	Particulate lb/ton	kg/Mt	Sulfur oxides ^b lb/ton	kg/Mt	Carbon monoxide lb/ton	kg/Mt	Hydrocarbons ^c lb/ton	kg/Mt	Nitrogen oxides ^d lb/ton	kg/Mt
Industrial/commercial										
Multiple chambers ^e	7	3.5	2.5 ^f	1.25	10	5	3	1.5	3	1.5
Single chamber ^g	15	7.5	2.5 ^f	1.25	20	10	15	7.5	2	1
Trench^h										
Wood	13	6.5	0.1 ⁱ	0.05	J	J	J	J	4	2
Rubber tires	138	89	J	J	J	J	J	J	J	J
Municipal refuse	37	18.5	2.5 ^f	1.25	J	J	J	J	J	J
Flue-fed single chamber ^k	30	15	0.5	0.25	20	10	15	7.5	3	1.5
Flue-fed (modified) ^{l,m}	6	3	0.5	0.25	10	5	3	1.5	10	5
Domestic single chamber										
Without primary burner ⁿ	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner ^o	7	3.5	0.5	0.25	Neg.	Neg.	2	1	2	1
Pathological ^p	8	4	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	3	1.5

^a Average factors, based on EPA procedures for incinerator stack testing. Neg = negligible.^b Expressed as sulfur dioxide.^c Expressed as methane.^d Expressed as nitrogen dioxide.^e References 3, 7-10.^f Based on municipal incinerator data.^g References 5, 7-8, 10.^h Reference 5.ⁱ Based on data for wood combustion in conical burners.^j Not available.^k References 3, 8-12.^l With afterburners and draft controls.^m References 3, 10-11.ⁿ References 7-8.^o Reference 7.^p References 3, 13.

dependent on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant and are caused by poor combustion resulting from improper combustor design or operating conditions. Nitrogen oxide emissions increase with an increase in the temperature of the combustion zone, an increase in the residence time in the combustion zone before quenching, and an increase in the excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.¹³

References for Section 2.1

1. Municipal Waste Combustion Industry Profile - Facilities Subject To Section 111(d) Guidelines, Radian Corporation, Research Triangle Park, NC, prepared for U. S. Environmental Protection Agency, September 16, 1988.
2. Municipal Waste Combustion Study - Combustion Control Of Organic Emissions, EPA/530-SW-87-021-c, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1987, p. 6-2.
3. Municipal Waste Combustion Retrofit Study (Draft), Radian Corporation, Research Triangle Park, NC, prepared for U. S. Environmental Protection Agency, August 5, 1988, p. 6-4.
4. Air Pollution Control At Resource Recovery Facilities, California Air Resources Board, Sacramento, CA, May 24, 1984.
5. Control Of NO_x Emissions from Municipal Waste Combustors, Radian Corporation, Research Triangle Park, NC, prepared for U. S. Environmental Protection Agency, February 3, 1989.
6. H. Vogg and L. Stieglitz, Chemosphere, Volume 15, 1986.
7. Emission Factor Documentation For AP-42 Section 2.1.1: Municipal Waste Combustion, EPA-450/4-90-016, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1990.
8. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.
9. Control Techniques For Carbon Monoxide Emissions From Stationary Sources, AP-65, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1970.
10. Air Pollution Engineering Manual, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1967.
11. J. DeMarco. et al., Incinerator Guidelines 1969, SW. 13TS, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1969.
12. J. O. Brukle, J. A. Dorsey, and B. T. Riley, "The Effects Of Operating Variables And Refuse Types On Emissions From A Pilot-scale Trench Incinerator", Proceedings Of The 1968 Incinerator Conference, American Society Of Mechanical Engineers, New York, NY, May 1968.

13. Walter R. Nessen, Systems Study Of Air Pollution From Municipal Incineration, Contract Number CPA-22-69-23, Arthur D. Little, Inc. Cambridge, MA, March 1970.
14. C. V. Kanter, R. G. Lunche, and A. P. Fururich, "Techniques For Testing Air Contaminants From Combustion Sources", Journal Of The Air Pollution Control Association, 6(4): 191-199, February 1957.
15. J. L. Stear, Municipal Incineration: A Review Of Literature, AP-79, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1971.
16. E. R. Kaiser, Refuse Reduction Processes In Proceedings Of Surgeon General's Conference On Solid Waste Management, PHS 1729, Public Health Service, Washington, DC, 1967.
17. Unpublished source test data on incinerators, Resources Research, Incorporated, Reston, VA, 1966-1969.
18. E. R. Kaiser, et al., Modifications To Reduce Emissions From A Flue-fed Incinerator, Report Number 552.2, College Of Engineering, New York University, June 1959, pp. 40 and 49.
19. Communication between Resources Research, Incorporated, Reston, VA, and Division Of Air Quality Control, Maryland State Department Of Health, Baltimore, MD, 1969.
20. Unpublished data on incinerator testing, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1970.

2.5 SEWAGE SLUDGE INCINERATION

There are currently almost 200 sewage sludge incineration (SSI) plants in operation in the United States. Three main types of incinerators are used: multiple hearth, fluidized bed, and electric infrared. Some sludge is co-fired with municipal solid waste in combustors based on refuse combustion technology. Refuse co-fired with sludge in combustors based on sludge incinerating technology is limited to multiple hearth incinerators only.

Over 80 percent of the identified operating sludge incinerators are of the multiple hearth design. About 15 percent are fluidized bed combustors and 3 percent are electric. The remaining combustors co-fire refuse with sludge. Most sludge incinerators are located in the Eastern United States, though there are a significant number on the West Coast. New York has the largest number of facilities with 28. Pennsylvania and Michigan have the next-largest numbers of facilities with 20 and 19 sites, respectively.

2.5.1 Process Description^{1,2}

Types of incineration described in this section include:

- Multiple hearth
- Fluidized bed
- Electric
- Single hearth cyclone
- Rotary kiln
- High pressure, wet air oxidation
- Co-incineration with refuse

2.5.1.1 Multiple Hearth Furnaces

The multiple hearth furnace was originally developed for mineral ore roasting nearly a century ago. The air-cooled variation has been used to incinerate sewage sludge since the 1930s. A cross section diagram of a typical multiple hearth furnace is shown in Figure 2.5-1. The basic multiple hearth furnace (MHF) is cylinder shaped and oriented vertically. The outer shell is constructed of steel, lined with refractory, and surrounds a series of horizontal refractory hearths. A hollow cast iron rotating shaft runs through the center of the hearths. Cooling air is introduced into the shaft by a fan located at its base. Attached to the central shaft are rabble arms, which extend above the hearths. Each rabble arm is equipped with a number of teeth, approximately 6 inches in length, and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in, to the inside out, between hearths. Typically, the upper and lower hearths are fitted with 4 rabble arms, and the middle hearths are fitted with two. Burners, providing auxiliary heat, are located in the sidewalls of the hearths.

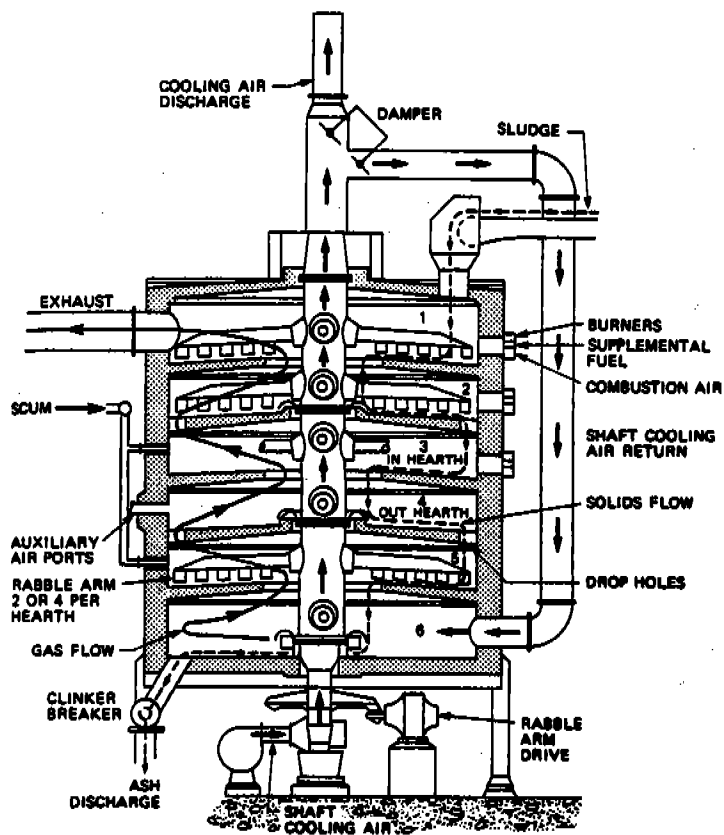


Figure 2.5-1. Cross section of a multiple hearth furnace.

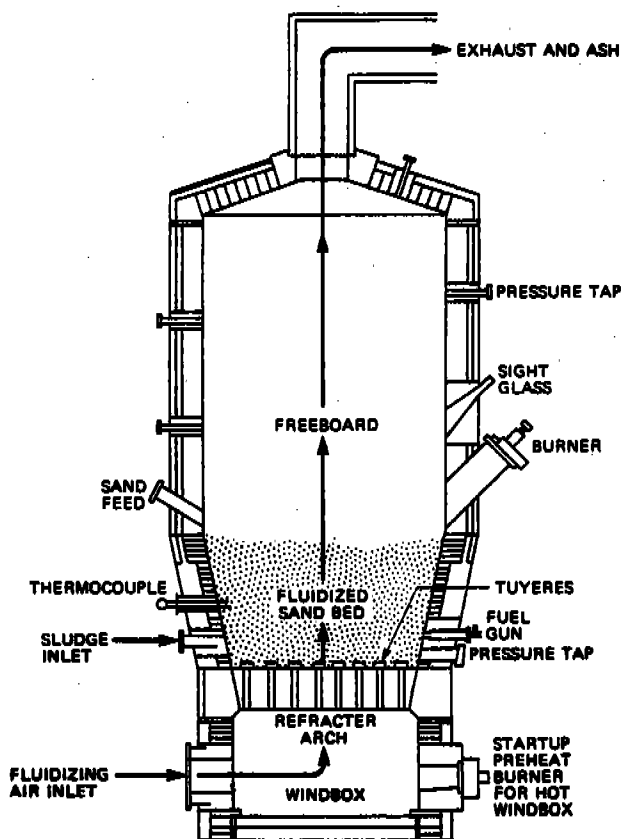


Figure 2.5-2. Cross section of a fluidized bed furnace.

Partially dewatered sludge is fed onto the perimeter of the top hearth. The motion of the rabble arms rakes the sludge toward the center shaft where it drops through holes located at the center of the hearth. In the next hearth the sludge is raked in the opposite direction. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen, and is arranged so that sludge depth of about one inch is maintained in each hearth at the design sludge flow rate.

Scum may also be fed to one or more hearths of the incinerator. Scum is the material that floats on wastewater. It is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float. Scum may be removed from many treatment units including preaeration tanks, skimming tanks, and sedimentation tanks. Quantities of scum are generally small compared to those of other wastewater solids.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion, or all, of this air is then taken from the top of the shaft and recirculated into the lowermost hearth as preheated combustion air. Shaft cooling air which is not circulated back into the furnace is ducted into the stack downstream of the air pollution control devices. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth. Provisions are usually made to inject ambient air directly into on the middle hearths as well.

From the standpoint of the overall incineration process, multiple hearth furnaces can be divided into three zones. The upper hearths comprise the drying zone where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 425 and 760°C (800 and 1400°F). Sludge combustion occurs in the middle hearths (second zone) as the temperature is increased to about 925°C (1700°F). The combustion zone can be further subdivided into the upper middle hearths where the volatile gases and solids are burned, and the lower middle hearths where most of the fixed carbon is combusted. The third zone, made up of the lowermost hearth(s), is the cooling zone. In this zone the ash is cooled as its heat is transferred to the incoming combustion air.

Multiple hearth furnaces are sometimes operated with afterburners to further reduce odors and concentrations of unburned hydrocarbons. In afterburning, furnace exhaust gases are ducted to a chamber where they are mixed with supplemental fuel and air and completely combusted. Some incinerators have the flexibility to allow sludge to be fed to a lower hearth, thus allowing the upper hearth(s) to function essentially as an afterburner.

Under normal operating conditions, 50 to 100 percent excess air must be added to a MHF in order to ensure complete combustion of the sludge. Besides enhancing contact between fuel and oxygen in the furnace, these relatively high rates of excess air are necessary to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When an inadequate amount of excess air is available, only partial oxidation of the carbon will occur with a resultant increase in emissions of carbon monoxide, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption.

Some MHFs have been designed to operate in a starved air mode. Starved air combustion (SAC) is, in effect, incomplete combustion. The key to SAC is the use of less than theoretical quantities of air in the furnace, 30 to 90 percent of stoichiometric quantities. This makes SAC more fuel efficient than an excess air mode MHF. The SAC reaction products are combustible gases, tars and oils, and a solid char that can have appreciable heating value. The most effective utilization of these products is by burning of the total gas stream with subsequent heat recovery. When an SAC MHF is combined with an afterburner, an overall excess air rate of 25 to 50 percent can be maintained (as compared to 75 to 200 percent overall for an excess air MHF with an afterburner).

Multiple hearth furnace emissions are usually controlled by a venturi scrubber, an impingement tray scrubber, or a combination of both. Wet cyclones are also used.

2.5.1.2 Fluidized Bed Incinerators

Fluidized bed technology was first developed by the petroleum industry to be used for catalyst regeneration. Figure 2.5-2 shows the cross section diagram of a fluidized bed furnace. Fluidized bed furnaces (FBF) are cylindrically shaped and oriented vertically. The outer shell is constructed of steel, and is lined with refractory. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand, approximately 0.75 meters (2.5 feet) thick, rests upon the grid. Two general configurations can be distinguished on the basis of how the fluidizing air is injected into the furnace. In the "hot windbox" design the combustion air is first preheated by passing through a heat exchanger where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox.

Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres, at pressure of from 20 to 35 kilopascals (3 to 5 pounds per square inch gauge), simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 750 to 925°C (1400 to 1700°F) are maintained in the bed. Residence times are on the order of 2 to 5 seconds. As the sludge burns, fine ash particles are carried out the top of the furnace. Some sand is also removed in the air stream; sand make-up requirements are on the order of 5 percent for every 300 hours of operation.

The overall process of combustion of the sludge occurs in two zones. Within the bed itself (zone 1) evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the second zone, (freeboard area) the remaining free carbon and combustible gases are burned. The second zone functions essentially as an after burner.

Fluidization achieves nearly ideal mixing between the sludge and the combustion air and the turbulence facilitates the transfer of heat from the hot sand to the sludge. The most noticeable impact of the better burning atmosphere provided by a fluidized bed incinerator is seen in the limited amount of excess air required for complete combustion of the sludge. These incinerators can achieve complete combustion with 20 to 50 percent excess air, about half the amount of excess air typically required for incinerating sewage

sludge in multiple hearth furnaces. As a consequence, FBF incinerators have generally lower fuel requirements compared to MHF incinerators.

Fluidized bed incinerators most often have venturi scrubbers or venturi/impingement tray scrubber combinations for emissions control.

2.5.1.3 Electric Incinerators

Electric furnace technology is new compared to other sludge combustor designs; the first electric furnace was installed in 1975. Electric incinerators consist of a horizontally oriented, insulated furnace. A woven wire belt conveyor extends the length of the furnace and infrared heating elements are located in the roof above the conveyor belt. Combustion air is preheated by the flue gases and is injected into the discharge end of the furnace. Electric incinerators consist of a number of prefabricated modules, which can be linked together to provide the necessary furnace length. A cross section of an electric furnace is shown in Figure 2.5-3.

The dewatered sludge cake is conveyed into one end of the incinerator. An internal roller mechanism levels the sludge into a continuous layer approximately one inch thick across the width of the belt. The sludge is sequentially dried and then burned as it moves beneath the infrared heating elements. Ash is discharged into a hopper at the opposite end of the furnace. The preheated combustion air enters the furnace above the ash hopper and is further heated by the outgoing ash. The direction of air flow is countercurrent to the movement of the sludge along the conveyor. Exhaust gases leave the furnace at the feed end. Excess air rates vary from 20 to 70 percent.

When compared to MHF and FBF technologies, the electric furnace offers the advantage of lower capital cost, especially for smaller systems. However, electricity costs in some areas may make an electric furnace infeasible. One other concern is replacement of various components such as the woven wire belt and infrared heaters, which have 3 to 5 year lifetimes.

Electric incinerators are usually controlled with a venturi scrubber or some other wet scrubber.

2.5.1.4 Other Technologies

A number of other technologies have been used for incineration of sewage sludge including cyclonic reactors, rotary kilns and wet oxidation reactors. These processes are not in widespread use in the United States and will be discussed only briefly.

The cyclonic reactor is designed for small capacity applications. It is constructed of a vertical cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the chamber tangentially at high velocities. The sludge is sprayed radially toward the hot refractory walls. Combustion is rapid: the residence time of the sludge in the chamber is on the order of 10 seconds. The ash is removed with the flue gases.

Rotary kilns are also generally used for small capacity applications. The kiln is inclined slightly from the horizontal plane, with the upper end

receiving both the sludge feed and the combustion air. A burner is located at the lower end of the kiln. The circumference of the kiln rotates at a speed of about 6 inches per second. Ash is deposited into a hopper located below the burner.

The wet oxidation process is not strictly one of incineration; it instead utilizes oxidation at elevated temperature and pressure in the presence of water (flameless combustion). Thickened sludge, at about six percent solids, is first ground and mixed with a stoichiometric amount of compressed air. The slurry is then pressurized. The mixture is then circulated through a series of heat exchangers before entering a pressurized reactor. The temperature of the reactor is held between 175 and 315°C (350 and 600°F). The pressure is normally 7000 to 12,500 kilopascals (1000 to 1800 pounds per square grade). Steam is usually used for auxiliary heat. The water and remaining ash are circulated out the reactor and are finally separated in a tank or lagoon. The liquid phase is recycled to the treatment plant. Off-gases must be treated to eliminate odors: wet scrubbing, afterburning or carbon absorption may be used.

2.5.1.5 Co-incineration With Refuse

Wastewater treatment plant sludge generally has a high water content and in some cases, fairly high levels of inert materials. As a result, its net fuel value is often low. If sludge is combined with other combustible materials in a co-combustion scheme, a furnace feed can be created that has both a low water concentration and a heat value high enough to sustain combustion with little or no supplemental fuel.

Virtually any material that can be burned can be combined with sludge in a co-combustion process. Common materials for co-combustion are coal, municipal solid waste (MSW), wood waste and agricultural waste. Thus, a municipal or industrial waste can be disposed of while providing an autogenous (self-sustaining) sludge feed, thereby solving two disposal problems.

There are two basic approaches to combusting sludge with municipal solid waste, 1) use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and 2) use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace. With the latter, MSW is processed by removing noncombustibles, shredding, air classifying, and screening. Waste that is more finely processed is less likely to cause problems such as severe erosion of the hearths, poor temperature control, and refractory failures.

2.5.2 Emissions And Controls¹⁻³

Sewage sludge incinerators potentially emit significant quantities of pollutants. The major pollutants emitted are: 1) particulate matter, 2) metals, 3) carbon monoxide (CO), 4) nitrogen oxides (NO_x), 5) sulfur dioxide (SO₂) and 6) unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion (PIC) including toxic organic compounds.

Uncontrolled particulate emission rates vary widely depending on the type of incinerator, the volatiles and moisture content of the sludge, and the operating practices employed. Generally, uncontrolled particulate emissions

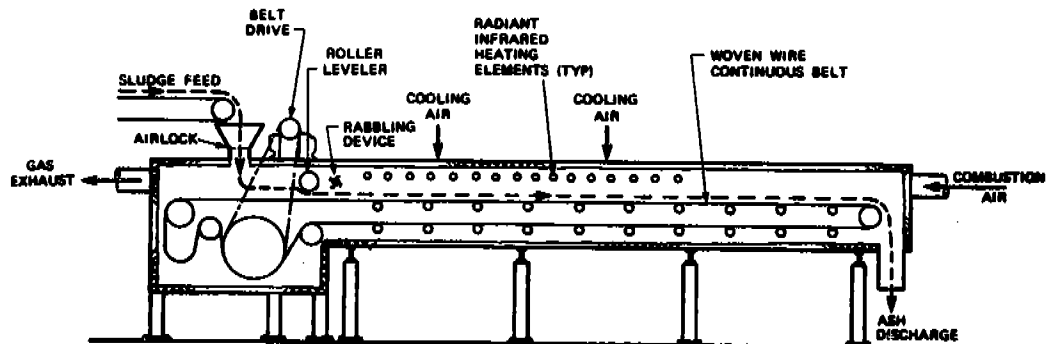


Figure 2.5-3. Cross section of an electric infrared furnace.

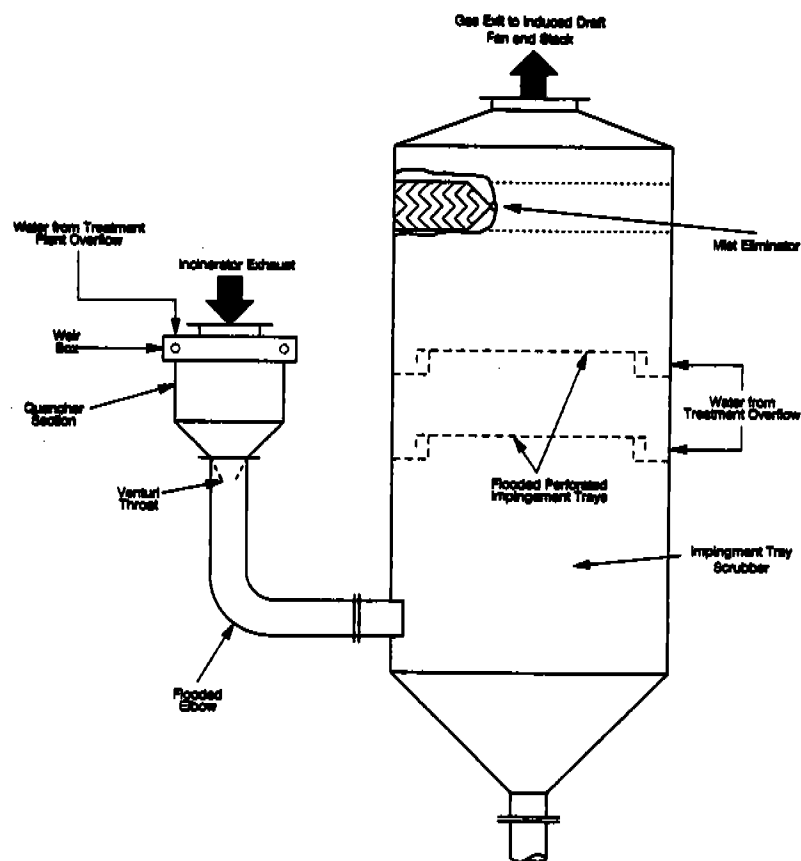


Figure 2.5-4. Venturi/impingement tray scrubber.

are highest from fluidized bed incinerators because suspension burning results in much of the ash being carried out of the incinerator with the flue gas. Uncontrolled emissions from multiple hearth and fluidized bed incinerators are extremely variable, however. Electric incinerators appear to have the lowest rates of uncontrolled particulate release of the three major furnace types, possibly because the sludge is not disturbed during firing. In general, higher airflow rates increase the opportunity for particulate matter to be entrained in the exhaust gases. Sludge with low volatile content or high moisture content may compound this situation by requiring more supplemental fuel to burn. As more fuel is consumed, the amount of air flowing through the incinerator is also increased. However, no direct correlation has been established between air flow and particulate emissions.

Metals emissions are affected by flue gas temperature and the level of particulate matter control, since metals which are volatilized in the combustion zone condense in the exhaust gas stream. Most metals (except mercury) are associated with fine particulate and are removed as the fine particulates are removed.

Carbon monoxide is formed when available oxygen is insufficient for complete combustion or when excess air levels are too high, resulting in lower combustion temperatures.

Nitrogen and sulfur oxide emissions are primarily the result of oxidation of nitrogen and sulfur in the sludge. Therefore, these emissions can vary greatly based on local and seasonal sewage characteristics.

Emissions of volatile organic compounds also vary greatly with incinerator type and operation. Incinerators with countercurrent air flow such as multiple hearth designs provide the greatest opportunity for unburned hydrocarbons to be emitted. In the MHF, hot air and wet sludge feed are contacted at the top of the furnace. Any compounds distilled from the solids are immediately vented from the furnace at temperatures too low to completely destruct them.

Particulate emissions from sewage sludge incinerators have historically been controlled by wet scrubbers, since the associated sewage treatment plant provides both a convenient source and a good disposal option for the scrubber water. The types of existing sewage sludge incinerator controls range from low pressure drop spray towers and wet cyclones to higher pressure drop venturi scrubbers and venturi/impingement tray scrubber combinations. A few electrostatic precipitators are employed, primarily where sludge is co-fired with municipal solid waste. The most widely used control device applied to a multiple hearth incinerator is the impingement tray scrubber. Older units use the tray scrubber alone while combination venturi/impingement tray scrubbers are widely applied to newer multiple hearth incinerators and to fluidized bed incinerators. Most electric incinerators and many fluidized bed incinerators use venturi scrubbers only.

In a typical combination venturi/impingement tray scrubber (shown in Figure 2.5-4), hot gas exits the incinerator and enters the precooling or quench section of the scrubber. Spray nozzles in the quench section cool the incoming gas and the quenched gas then enters the venturi section of the control device.

Venturi water is usually pumped into an inlet weir above the quencher. The venturi water enters the scrubber above the throat and floods the throat completely. This eliminates build-up of solids and reduces abrasion. Turbulence created by high gas velocity in the converging throat section deflects some of the water traveling down the throat into the gas stream. Particulate matter carried along with the gas stream impacts on these water particles and on the water wall. As the scrubber water and flue gas leave the venturi section, they pass into a flooded elbow where the stream velocity decreases, allowing the water and gas to separate. Most venturi sections come equipped with variable throats. By restricting the throat area within the venturi, the linear gas velocity is increased and the pressure drop is subsequently increased. Up to a certain point, increasing the venturi pressure drop increases the removal efficiency. Venturi scrubbers typically maintain 60 to 99 percent removal efficiency for particulate matter, depending on pressure drop and particle size distribution.

At the base of the flooded elbow, the gas stream passes through a connecting duct to the base of the impingement tray tower. Gas velocity is further reduced upon entry to the tower as the gas stream passes upward through the perforated impingement trays. Water usually enters the trays from inlet ports on opposite sides and flows across the tray. As gas passes through each perforation in the tray, it creates a jet which bubbles up the water and further entrains solid particles. At the top of the tower is a mist eliminator to reduce the carryover of water droplets in the stack effluent gas. The impingement section can contain from one to four trays, but most systems for which data are available have two or three trays.

Emission factors and emission factor ratings for sludge incinerators are shown in Table 2.5-1. Table 2.5-2 shows the cumulative particle size distribution and size specific emission factors for sewage sludge incinerators. Figures 2.5-5, 2.5-6, and 2.5-7 show cumulative particle size distribution and size-specific emission factors for multiple-hearth, fluidized-bed, and electric infrared incinerators, respectively.

TABLE 2.5-1. EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS^a

Pollutant	Cut diameter, microns	Multiple hearth			Fluidized bed			Electric infrared		
		Uncontrolled, kg/Mg (lb/ton) ^b	scrubber, kg/Mg (lb/ton) ^b	Emission Factor Rating	Uncontrolled, kg/Mg (lb/ton) ^b	scrubber, kg/Mg (lb/ton) ^b	Emission Factor Rating	Uncontrolled, kg/Mg (lb/ton) ^b	scrubber, kg/Mg (lb/ton) ^b	Emission Factor Rating
Particulate	0.625	0.30 (0.60)	0.07 (0.14) ^c	E	NA	0.08 (0.16) ^d	E	0.50 (1.0)	0.30 (0.60) ^e	E
	1.0	0.47 (0.94)	0.08 (0.16)			0.15 (0.30)		0.60 (1.2)	0.35 (0.70)	
	2.5	1.1 (2.2)	0.09 (0.18)			0.18 (0.36)		1.0 (2.0)	0.50 (1.0)	
	5.0	2.1 (4.2)	0.10 (0.20)			0.20 (0.40)		1.7 (3.4)	0.70 (1.4)	
	10.0	4.1 (8.2)	0.11 (0.22)			0.22 (0.44)		3.0 (6.0)	1.0 (2.0)	
	15.0	6.0 (12)	0.12 (0.24)			0.23 (0.46)		4.3 (8.6)	1.2 (2.4)	
Total particulate		42 (84)	0.89 (1.8) ^e	C	NA	0.33 (0.66) ^e	C	4 (8)	1 (2) ^e	E
Lead		0.05 (0.10)	0.02 (0.04) ^e	C	NA	0.003 (0.006) ^e	D	NA	NA	
Sulfur dioxide ^f		10 (20)	2 (4) ^e	D	10 (20)	2.0 (4.0) ^e	D	10 (20)	2.0 (4.0) ^e	D
Nitrogen oxides		5.5 (11)	2.5 (5.0) ^e	C	NA	2.2 (4.4) ^e	D	4 (8)	3 (6) ^e	E
Carbon monoxide		36 (72)	2 (4) ^e	C	NA	2 (4) ^e	E	NA	NA	
Volatile organics										
Methane		NA	2.3 (4.6) ^e	D	NA	1 (2) ^e	E	NA	NA	
Nonmethane		0.85 (1.7)	0.85 (1.7) ^e	D	NA	NA		NA	NA	

^aReference 5. NA = not available.^bExpressed in units of dried sludge. Particulate figures in parentheses are cumulative.^cImpingement scrubber.^dVenturi scrubber.^eImpingement, venturi and/or cyclone scrubbers.^fBecause data were limited, an average for all three types of incinerators is presented.

TABLE 2.5-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS^a

Particle size, microns	Cumulative mass % \leq stated size						Cumulative emission factor, kg/Mg (lb/ton)					
	Uncontrolled			Controlled			Uncontrolled			Controlled		
	MH ^b	FB ^c	EI ^d	MH ^b	FB ^c	EI ^d	MH ^b	FB ^c	EI ^d	MH ^b	FB ^c	EI ^d
15	15	NA	43	30	7.7	60	6.0 (12)	NA	4.3 (8.6)	0.12 (0.24)	0.23 (0.46)	1.2 (2.4)
10	10	NA	30	27	7.3	50	4.1 (8.2)	NA	3.0 (6.0)	0.11 (0.22)	0.22 (0.44)	1.0 (2.0)
5.0	5.3	NA	17	25	6.7	35	2.1 (4.2)	NA	1.7 (3.4)	0.10 (0.20)	0.20 (0.40)	0.70 (1.4)
2.5	2.8	NA	10	22	6.0	25	1.1 (2.2)	NA	1.0 (2.0)	0.09 (0.18)	0.18 (0.36)	0.50 (1.0)
1.0	1.2	NA	6.0	20	5.0	18	0.47 (0.94)	NA	0.60 (1.2)	0.08 (0.16)	0.15 (0.30)	0.35 (0.70)
0.625	0.75	NA	5.0	17	2.7	15	0.30 (0.60)	NA	0.50 (1.0)	0.07 (0.14)	0.08 (0.16)	0.30 (0.60)
TOTAL	100	100	100	100	100	100	40 (80)	NA	10 (20)	0.40 (0.80)	3.0 (6.0)	2.0 (4.0)

^aReference 5. NA = not available.

^bMH = multiple hearth.

^cFB = fluidized bed.

^dEI = electric infrared.

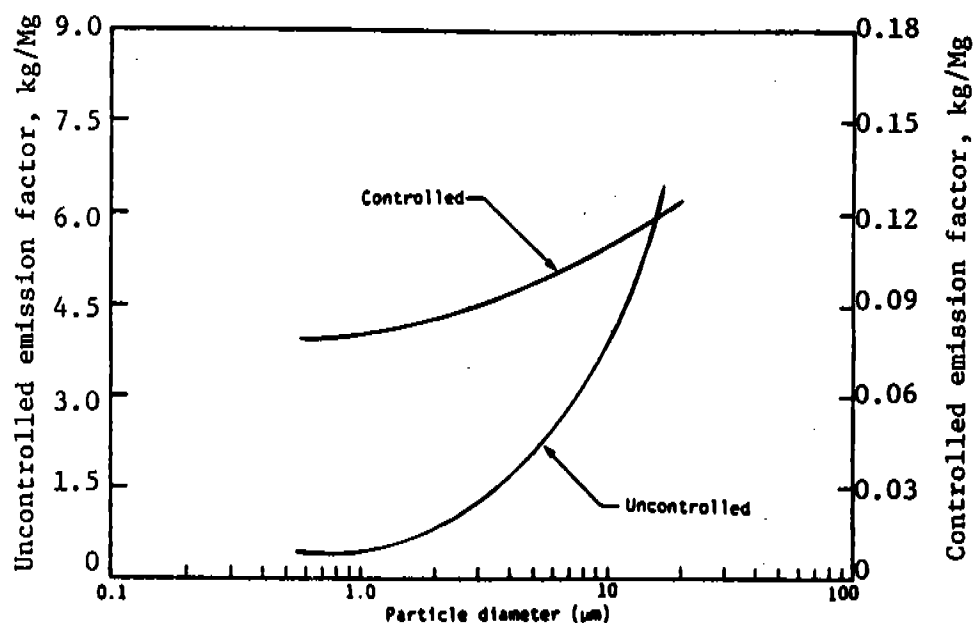


Figure 2.5-5. Cumulative particle size distribution and size-specific emission factors for multiple-hearth incinerators.

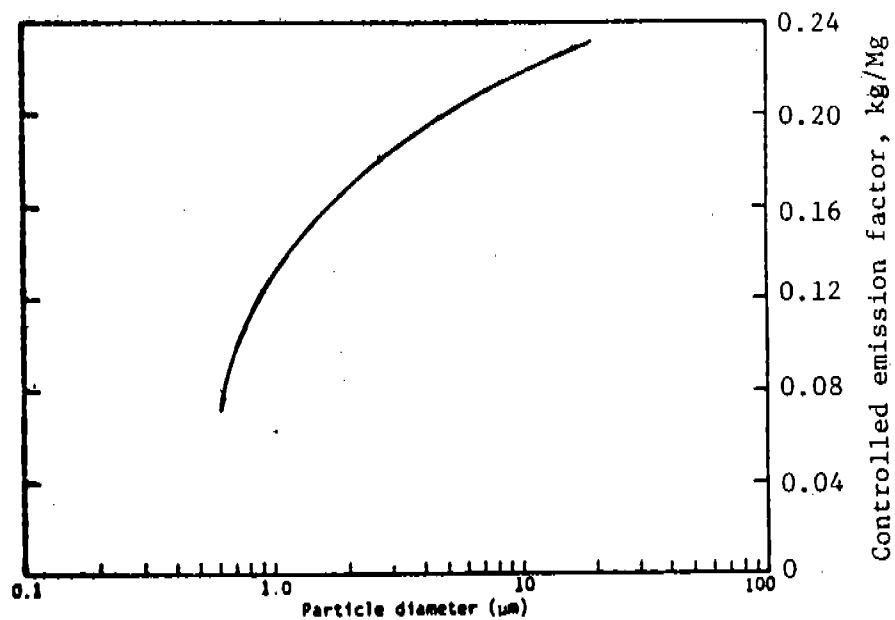


Figure 2.5-6. Cumulative particle size distribution and size-specific emission factors for fluidized-bed incinerators.

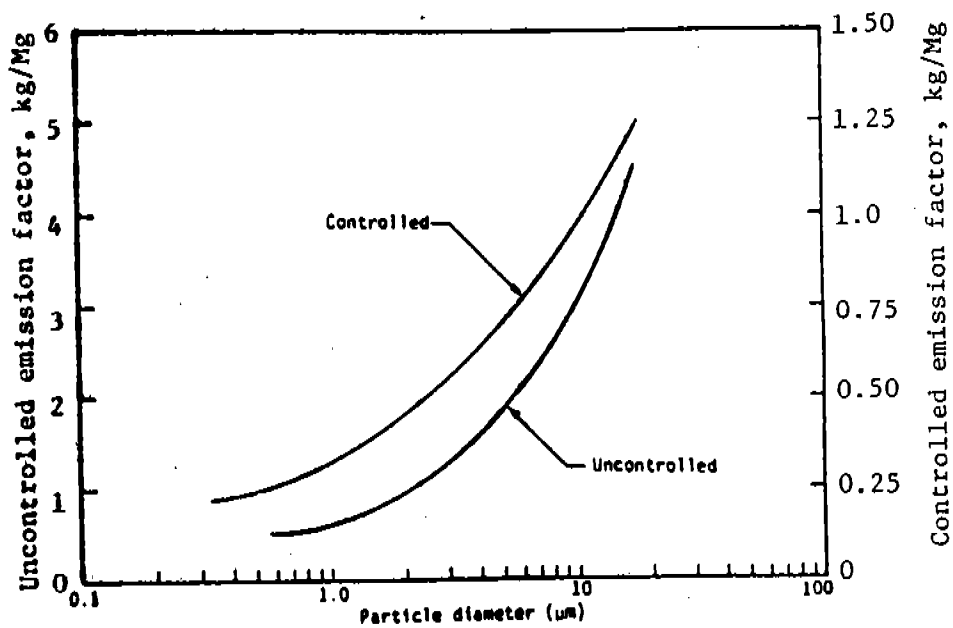


Figure 2.5-7. Cumulative particle size distribution and size-specific emission factors for electric(infrared) incinerators.

References for Section 2.5

1. Second Review Of Standards Of Performance For Sewage Sludge Incinerators, EPA-450/3-84-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1984.
2. Process Design Manual For Sludge Treatment And Disposal, EPA-625/1-79-011, U. S. Environmental Protection Agency, Cincinnati, OH, September 1979.
3. Control Techniques For Particulate Emissions From Stationary Sources - Volume 1, EPA-450/3-81-005a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1982.
4. Emission Factor Documentation For AP-42 Section 2.5: Sewage Sludge Incineration, EPA-450/4-90-017, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1990.

4.2.2.13 Magnetic Tape Manufacturing Industry¹⁻⁹

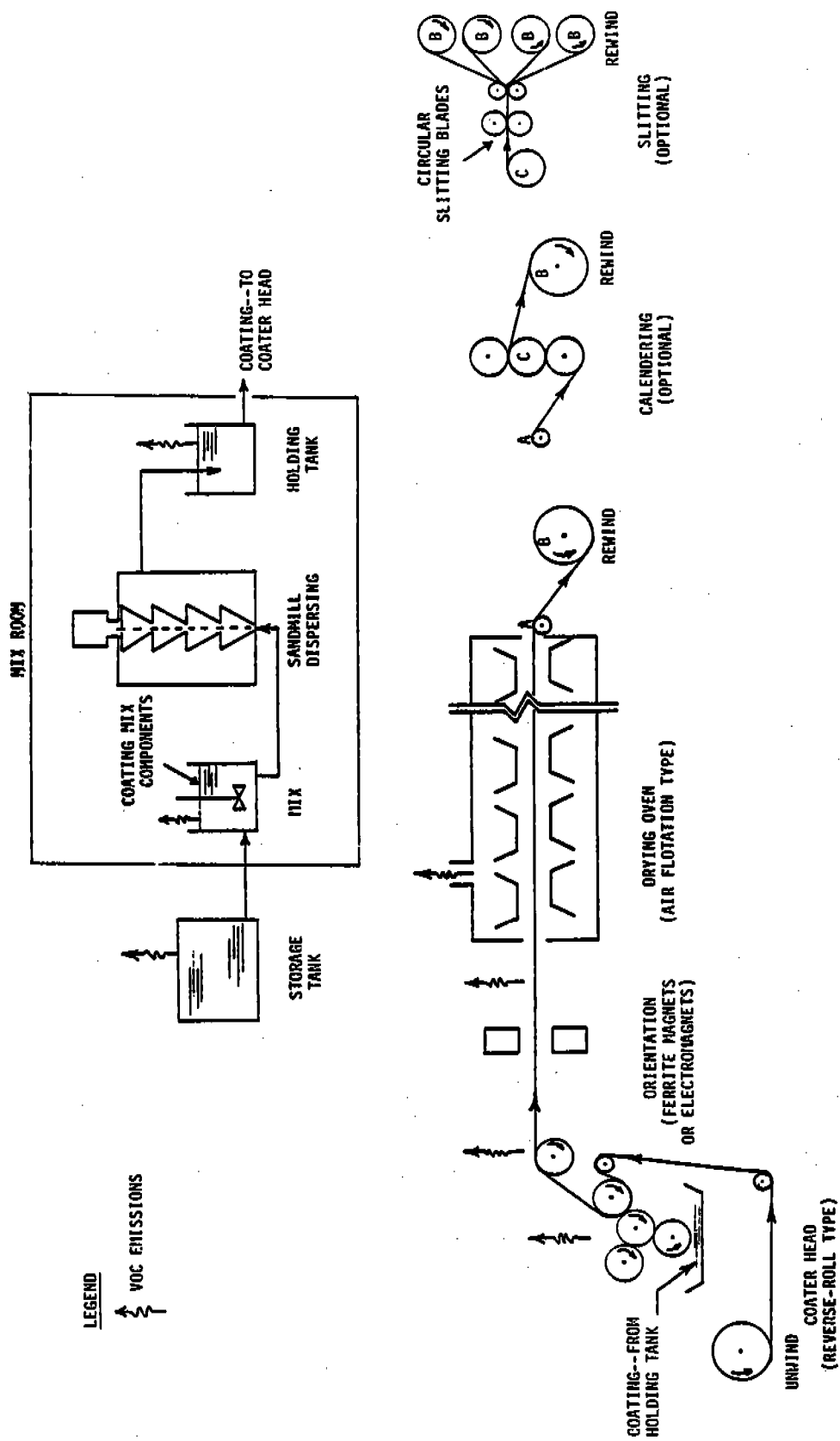
Magnetic tape manufacturing is a subcategory of industrial paper coating, which includes coating of foil and plastic film. In the manufacturing process, a mixture of magnetic particles, resins and solvents is coated on a thin plastic film or "web". Magnetic tape is used largely for audio and video recording and computer information storage. Other uses include magnetic cards, credit cards, bank transfer ribbons, instrumentation tape, and dictation tape. The magnetic tape coating industry is included in two Standard Industrial Classification codes, 3573 (Electronic Computing Equipment) and 3679 (Electronic Components Not Elsewhere Classified).

Process Description¹⁻² - The process of manufacturing magnetic tape consists of:

- 1) mixing the coating ingredients (including solvents)
- 2) conditioning the web
- 3) applying the coating to the web
- 4) orienting the magnetic particles
- 5) drying the coating in a drying oven,
- 6) finishing the tape by calendering, rewinding, slitting, testing, and packaging.

Figure 4.2.2.13-1 shows a typical magnetic tape coating operation, indicating volatile organic compound (VOC) emission points. Typical plants have from 5 to 12 horizontal or vertical solvent storage tanks, ranging in capacity from 3,800 to 75,700 liters (1,000 to 20,000 gallons), that are operated at or slightly above atmospheric pressure. Coating preparation equipment includes the mills, mixers, polishing tanks, and holding tanks used to prepare the magnetic coatings before application. Four types of coaters are used in producing magnetic tapes: extrusion (slot die), gravure, knife, and reverse roll (3- and 4-roll). The web may carry coating on one or both sides. Some products receive a nonmagnetic coating on the back. After coating, the web is guided through an orientation field, in which an electromagnet or permanent magnet aligns the individual magnetic particles in the intended direction. Webs from which flexible disks are to be produced do not go through the orientation process. The coated web then passes through a drying oven, where the solvents in the coating evaporate. Typically, air flotation ovens are used, in which the web is supported by jets of drying air. For safe operation, the concentration of solvent vapors is held between 10 and 40 percent of the lower explosive limit. The dry coated web may be passed through several calendering rolls to compact the coating and to smooth the surface finish. Nondestructive testing is performed on up to 100 percent of the final product, depending on the level of precision required of the final product. The web may then be slit into the desired tape widths. Flexible disks are punched from the finished web with a die. The final product is then packaged. Some plants ship the coated webs in bulk to other facilities for slitting and packaging.

High performance tapes require very clean production conditions, especially in the coating application and drying oven areas. Air supplied to

Figure 4.2.2.13-1. Schematic drawing of a magnetic tape coating plant.¹

these areas is conditioned to remove dust particles and to adjust the temperature and humidity. In some cases, "clean room" conditions are rigorously maintained.

Emissions And Controls¹⁻⁸ - The significant VOC emission sources in a magnetic tape manufacturing plant include the coating preparation equipment, the coating application and flashoff area, and the drying ovens. Emissions from the solvent storage tanks and the cleanup area are generally only a negligible percentage of total emissions.

In the mixing or coating preparation area, VOCs are emitted from the individual pieces of equipment during the following operations: filling of mixers and tanks; transfer of the coating; intermittent activities, such as changing the filters in the holding tanks; and mixing (if equipment is not equipped with tightly fitting covers). Factors affecting emissions in the mixing areas include the capacity of the equipment, the number of pieces of equipment, solvent vapor pressure, throughput, and the design and performance of equipment covers. Emissions will be intermittent or continuous, depending on whether the preparation method is batch or continuous.

Emissions from the coating application area result from the evaporation of solvent during use of the coating application equipment and from the exposed web as it travels from the coater to the drying oven (flashoff). Factors affecting emissions are the solvent content of the coating, line width and speed, coating thickness, volatility of the solvent(s), temperature, distance between coater and oven, and air turbulence in the coating area.

Emissions from the drying oven are of the remaining solvent that is driven off in the oven. Uncontrolled emissions at this point are determined by the solvent content of the coating when it reaches the oven. Because the oven evaporates all the remaining solvent from the coating, there are no process VOC emissions after oven drying.

Solvent type and quantity are the common factors affecting emissions from all operations in a magnetic tape coating facility. The rate of evaporation or drying depends on solvent vapor pressure at a given temperature and concentration. The most commonly used organic solvents are toluene, methyl ethyl ketone, cyclohexanone, tetrahydrofuran, and methyl isobutyl ketone. Solvents are selected for their cost, solvency, availability, desired evaporation rate, ease of use after recovery, compatibility with solvent recovery equipment, and toxicity.

Of the total uncontrolled VOC emissions from the mixing area and coating operation (application/flashoff area and drying oven), approximately 10 percent is emitted from the mixing area, and 90 percent from the coating operation. Within the coating operation, approximately 10 percent occurs in the application/flashoff area, and 90 percent in the drying oven.

A control system for evaporative emissions consists of two components, a capture device and a control device. The efficiency of the control system is determined by the efficiencies of the two components.

A capture device is used to contain emissions from a process operation and direct them to a stack or to a control device. Room ventilation systems, covers, and hoods are possible capture devices from coating preparation equipment. Room ventilation systems, hoods, and partial and total enclosures are typical capture devices used in the coating application area. A drying oven can be considered a capture device, because it both contains and directs VOC process emissions. The efficiency of a capture device or a combination of capture devices is variable and depends on the quality of design and the levels of operation and maintenance.

A control device is any equipment that has as its primary function the reduction of emissions to the atmosphere. Control devices typically used in this industry are carbon adsorbers, condensers and incinerators. Tightly fitting covers on coating preparation equipment may be considered both capture and control devices, because they can be used either to direct emissions to a desired point outside the equipment or to prevent potential emissions from escaping.

Carbon adsorption units use activated carbon to adsorb VOCs from a gas stream, after which the VOCs are desorbed and recovered from the carbon. Two types of carbon adsorbers are available, fixed bed and fluidized bed. Fixed bed carbon adsorbers are designed with a steam-stripping technique to recover the VOCs and to regenerate the activated carbon. The fluidized bed units used in this industry are designed to use nitrogen for VOC vapor recovery and carbon regeneration. Both types achieve typical VOC control efficiencies of 95 percent when properly designed, operated and maintained.

Condensers control VOC emissions by cooling the solvent-laden gas to the dew point of the solvent(s) and then collecting the droplets. There are two condenser designs commercially available, nitrogen (inert gas) atmosphere and air atmosphere. These systems differ in the design and operation of the drying oven (i. e., use of nitrogen or air in the oven) and in the method of cooling the solvent-laden air (i. e., liquified nitrogen or refrigeration). Both design types can achieve VOC control efficiencies of 95 percent.

Incinerators control VOC emissions by oxidation of the organic compounds into carbon dioxide and water. Incinerators used to control VOC emissions may be of thermal or catalytic design and may use primary or secondary heat recovery to reduce fuel costs. Thermal incinerators operate at approximately 890°C (1600°F) to assure oxidation of the organic compounds. Catalytic incinerators operate in the range of 400 to 540 C (750 to 1000 F) while using a catalyst to achieve comparable oxidation of VOCs. Both design types achieve a typical VOC control efficiency of 98 percent.

Tightly fitting covers control VOC emissions from coating preparation equipment by reducing evaporative losses. The parameters affecting the efficiency of these controls are solvent vapor pressure, cyclic temperature change, tank size, and product throughput. A good system of tightly fitting covers on coating preparation equipment reduces emissions by as much as 40 percent. Control efficiencies of 95 or 98 percent can be obtained by venting the covered equipment to an adsorber, condenser or incinerator.

When the efficiencies of a capture device and control device are known, the efficiency of the control system can be computed by the following equation:

$$\text{capture efficiency} \times \text{control device efficiency} = \text{control system efficiency}$$

The terms of this equation are fractional efficiencies rather than percentages. For instance, a system of hoods delivering 60 percent of VOC emissions to a 90 percent efficient carbon adsorber would have control system efficiency of 54 percent ($0.60 \times 0.90 = 0.54$). Table 4.2.2.13-1 summarizes control system efficiencies, which may be used to estimate emissions in the absence of measured data on equipment and coating operations.

TABLE 4.2.2.13-1. TYPICAL OF CONTROL EFFICIENCIES^a

Control technology	Control Efficiency ^b (%)
Coating Preparation Equipment	
Uncontrolled	0
Tightly fitting covers	40
Sealed covers with carbon adsorber/condenser	95
Coating Operation ^c	
Local ventilation with carbon adsorber/condenser	83
Partial enclosure with carbon adsorber/condenser	87
Total enclosure with carbon adsorber/condenser	93
Total enclosure with incinerator	95

^aReference 1.

^bTo be applied to uncontrolled emissions from indicated process area, not from entire plant.

^cIncludes coating application/flashoff area and drying oven.

Emission Estimation Techniques^{1,3-9} - In this industry, realistic emission estimates require solvent consumption data. The variations found in coating formulations, line speeds and products mean that no reliable inferences can be made otherwise.

In uncontrolled plants and in those where VOCs are recovered for reuse or sale, plantwide emissions can be estimated by performing a liquid material balance based on the assumption that all solvent purchased replaces that which has been emitted. Any identifiable and quantifiable side streams should be subtracted from this total. The liquid material balance may be performed using the following general formula:

$$\begin{array}{rcl} \text{solvent} & \text{quantifiable} & \text{VOC} \\ \text{purchased} - \text{solvent output} & = & \text{emitted} \end{array}$$

The first term encompasses all solvent purchased, including thinners, cleaning agents, and any solvent directly used in coating formulation. From this total, any quantifiable solvent outputs are subtracted. Outputs may include reclaimed solvent sold for use outside the plant or solvent contained in waste streams. Reclaimed solvent that is reused at the plant is not subtracted.

The advantages of this method are that it is based on data that are usually readily available, it reflects actual operations rather than theoretical steady state production and control conditions, and it includes emissions from all sources at the plant. Care should be taken not to apply this method over too short a time span. Solvent purchase, production and waste removal occur in cycles which may not coincide exactly.

Occasionally, a liquid material balance may be possible on a scale smaller than the entire plant. Such an approach may be feasible for a single coating line or group of lines, if served by a dedicated mixing area and a dedicated control and recovery system. In this case, the computation begins with total solvent metered to the mixing area, instead of with solvent purchased. Reclaimed solvent is subtracted from this volume, whether or not it is reused on the site. Of course, other solvent input and output streams must be accounted, as previously indicated. The difference between total solvent input and total solvent output is then taken to be the quantity of VOCs emitted from the equipment in question.

Frequently, the configuration of meters, mixing areas, production equipment, and controls will make the liquid material balance approach impossible. In cases where control devices destroy potential emissions, or where a liquid material balance is inappropriate for other reasons, plantwide emissions can be estimated by summing the emissions calculated for specific areas of the plant. Techniques for these calculations are presented below.

Estimating VOC emissions from a coating operation (application/flashoff area and drying oven) starts with the assumption that the uncontrolled emission level is equal to the quantity of solvent contained in the coating applied. In other words, all the VOC in the coating evaporates by the end of the drying process.

Two factors are necessary to calculate the quantity of solvent applied, solvent content of the coating and the quantity of coating applied. Coating solvent content can be either directly measured using EPA Reference Method 24 or estimated using coating formulation data usually available from the plant owner/operator. The amount of coating applied may be directly metered. If it is not, it must be determined from production data. These data should be

available from the plant owner/operator. Care should be taken in developing these two factors to assure that they are in compatible units. In cases where plant-specific data cannot be obtained, the information in Table 4.2.2.13-2 may be useful in approximating the quantity of solvent applied.

When an estimate of uncontrolled emissions is obtained, the controlled emissions level is computed by applying a control system efficiency factor:

$$(\text{uncontrolled VOC}) \times (1 - \text{control system efficiency}) = (\text{VOC emitted}).$$

TABLE 4.2.2.13-2. SELECTED COATING MIX PROPERTIES^a

Parameter	Unit	Range
Solids	weight %	15-50
	volume %	10-26
VOC	weight %	50-85
	volume %	74-90
Density of coating	kg/l	1.0-1.2
	lb/gal	8-10
Density of coating solids	kg/l	2.8-4.0
	lb/gal	23-33
Resins/binder	weight % of solids	15-21
Magnetic particles	weight % of solids	66-78
Density of magnetic material	kg/l	1.2-4.8
	lb/gal	10-40
Viscosity	Pa·s	2.7-5.0
	lb _f ·s/ft ²	0.06-0.10
Coating thickness		
Wet	μm	3.8-54
	mil	0.15-2.1
Dry	μm	1.0-11
	mil	0.04-0.4

^aReference 9. To be used when plant-specific data are unavailable.

As previously explained, the control system efficiency is the product of the efficiencies of the capture device and of the control device. If these values are not known, typical efficiencies for some combinations of capture and

control devices are presented in Table 4.2.2.13-1. It is important to note that these control system efficiencies apply only to emissions that occur within the areas serviced by the systems. Emissions from sources such as process wastewater or discarded waste coatings may not be controlled at all.

In cases where emission estimates from the mixing area alone are desired, a slightly different approach is necessary. Here, uncontrolled emissions will consist of only that portion of total solvent that evaporates during the mixing process. A liquid material balance across the mixing area (i.e., solvent entering minus solvent content of coating applied) would provide a good estimate. In the absence of any measured value, it may be assumed, very approximately, that 10 percent of the total solvent entering the mixing area is emitted during the mixing process. When an estimate of uncontrolled mixing area emissions has been made, the controlled emission rate can be calculated as discussed previously. Table 4.2.2.13-1 lists typical overall control efficiencies for coating mix preparation equipment.

Solvent storage tanks of the size typically found in this industry are regulated by only a few states and localities. Tank emissions are generally small (130 kilograms per year or less). If an emissions estimate is desired, it can be computed using the equations, tables and figures provided in Section 4.3.2.

References For Section 4.2.2.13

1. Magnetic Tape Manufacturing Industry - Background Information For Proposed Standards, EPA-450/3-85-029a, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1985.
2. Control of Volatile Organic Emissions From Existing Stationary Sources - Volume II: Surface Coating Of Cans, Coils, Paper, Fabrics, Automobiles, And Light Duty Trucks, EPA 450/2-77-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1977.
3. C. Beall, "Distribution Of Emissions Between Coating Mix Preparation Area And The Coating Line", Memorandum file, Midwest Research Institute, Raleigh, NC, June 22, 1984.
4. C. Beall, "Distribution Of Emissions Between Coating Application/Flashoff Area And Drying Oven", Memorandum to file, Midwest Research Institute, Raleigh, NC, June 22, 1984.
5. Control Of Volatile Organic Emission From Existing Stationary Sources - Volume I: Control Methods For Surface-coating Operations, EPA-450/2-76-028, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1976.
6. G. Crane, Carbon Adsorption For VOC Control, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1982.

7. D. Mascone, "Thermal Incinerator Performance For NSPS", Memorandum, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 11, 1980.
8. D. Mascone, "Thermal Incinerator Performance For NSPS, Addendum", Memorandum, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 22, 1980.
9. C. Beall, "Summary Of Nonconfidential Information On U. S. Magnetic Tape Coating Facilities", Memorandum, with attachment, to file, Midwest Research Institute, Raleigh, NC, June 22, 1984.

4.2.2.14 Surface Coating Of Plastic Parts For Business Machines

4.2.2.14.1 General¹⁻²

Surface coating of plastic parts for business machines is defined as the process of applying coatings to plastic business machines parts to improve the appearance of the parts, to protect the parts from physical or chemical stress, and/or to attenuate electromagnetic interference/radio frequency interference (EMI/RFI) that would otherwise pass through plastic housings. Plastic parts for business machines are synthetic polymers formed into panels, housings, bases, covers, or other business machine components. The business machines category includes items such as typewriters, electronic computing devices, calculating and accounting machines, telephone and telegraph equipment, photocopiers and miscellaneous office machines.

The process of applying an exterior coating to a plastic part can include surface preparation, spray coating, and curing, with each step possibly being repeated several times. Surface preparation may involve merely wiping off the surface, or it could involve sanding and puttying to smooth the surface. The plastic parts are placed on racks or trays, or are hung on racks or hooks from an overhead conveyor track for transport among spray booths, flashoff areas and ovens. Coatings are sprayed onto parts in partially enclosed booths. An induced air flow is maintained through the booths to remove overspray and to keep solvent concentrations in the room air at safe levels. Although low temperature bake ovens (140° F or less) are often used to speed up the curing process, coatings also may be partially or completely cured at room temperature.

Dry filters or water curtains (in water wash spray booths) are used to remove overspray particles from the booth exhaust. In waterwash spray booths, most of the insoluble material is collected as sludge, but some of this material is dispersed in the water along with the soluble overspray components. Figure 4.2.2.14-1 depicts a typical dry filter spray booth, and Figure 4.2.2.14-2 depicts a typical water wash spray booth.

Many surface coating plants have only one manually operated spray gun per spray booth, and they interchange spray guns according to what type of coating is to be applied to the plastic parts. However, some larger surface coating plants operate several spray guns (manual or robotic) per spray booth, because coating a large volume of similar parts on conveyor coating lines makes production more efficient.

Spray coating systems commonly used in this industry fall into three categories, three coat, two coat, and single coat. The three coat system is the most common, applying a prime coat, a color or base coat, and a texture coat. Typical dry film thickness for the three coat system ranges from 1 to 3 mils for the prime coat, 1 to 2 mils for the color coat, and 1 to 5 mils for the texture coat. Figure 4.2.2.14-3 depicts a typical conveyorized coating line using the three-coat system. The conveyor line consists of three separate spray booths, each followed by a flashoff (or drying) area, all of

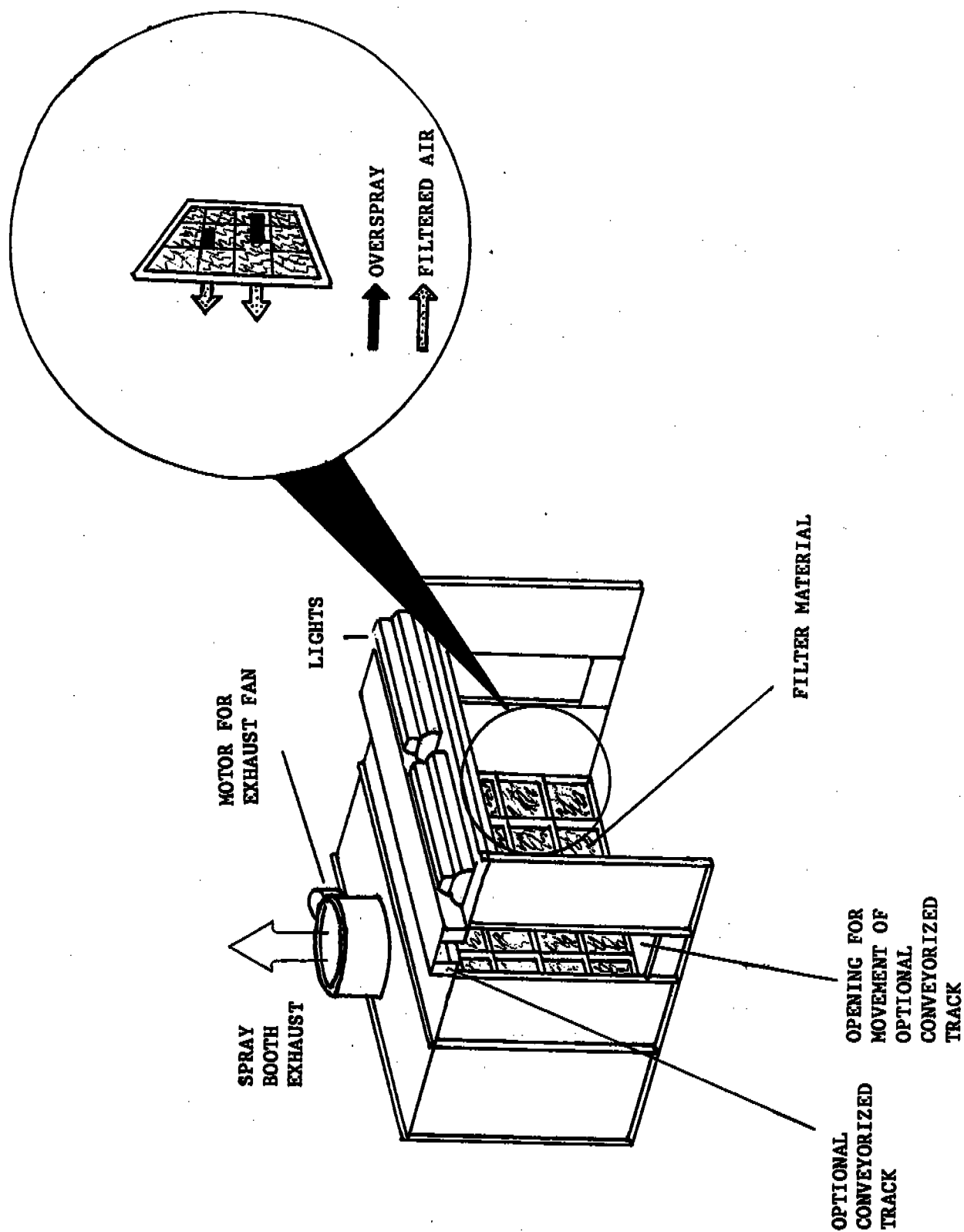


Figure 4.2.2.14-1. Typical dry filter spray booth. 3-4

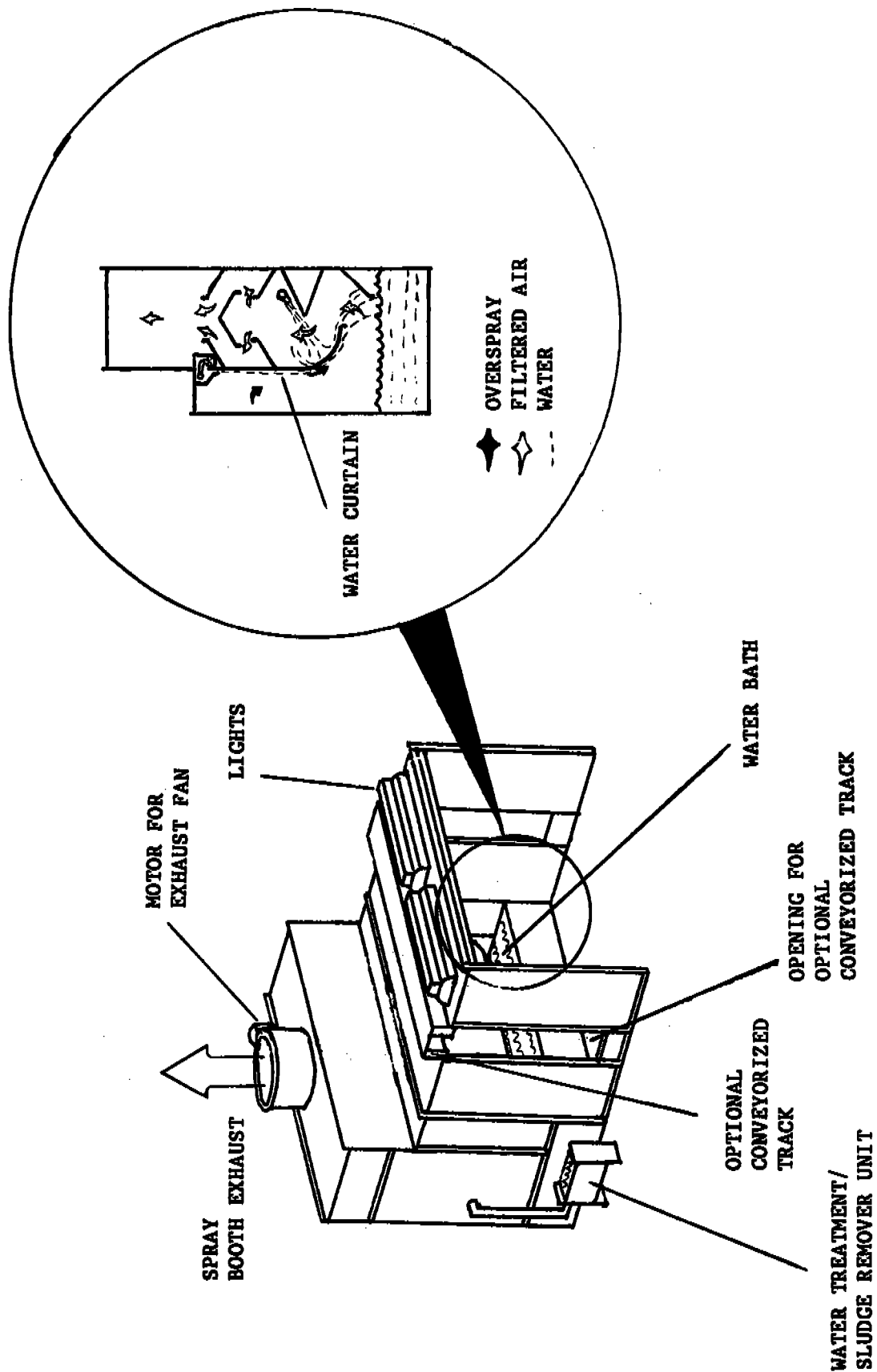


Figure 4.2.2.14-2. Typical waterwash spray booth.³

which is followed by a curing oven. A two coat system applies a color or base coat, then a texture coat. Typical dry film thickness for the two coat system is 2 mils for the color (or base) coat and 2 to 5 mils for the texture coat. The rarely used single coat system applies only a thin color coat, either to protect the plastic substrate or to improve color matching between parts whose color and texture are molded in. Less coating solids are applied with the single coat system than with the other systems. The dry film thickness applied for the single coat system depends on the function of the coating. If protective properties are desired, the dry film thickness must be at least 1 mil (.001 inches). For purposes of color matching among parts having molded-in color and texture, a dry film thickness of 0.5 mils or less is needed to avoid masking the molded-in texture. The process of applying 0.5 mils of coating or less for color matching is commonly known as "fog coating", "mist coating", or "uniforming".

The three basic spray methods used in this industry to apply decorative/exterior coatings are air atomized spray, air-assisted airless spray, and electrostatic air spray. Air atomized spray is the most widely used coating technique for plastic business machine parts. Air-assisted airless spray is growing in popularity but is still not frequently found. Electrostatic air spray is rarely used, because plastic parts are not conductive. It has been used to coat parts that have been either treated with a conductive sensitizer or plated with a thin film of metal.

Air atomized spray coating uses compressed air, which may be heated and filtered, to atomize the coating and to direct the spray. Air atomized spray equipment is compatible with all coatings commonly found on plastic parts for business machines.

Air-assisted airless spray is a variation of airless spray, a spray technique used in other industries. In airless spray coating, the coating is atomized without air by forcing the liquid coating through specially designed nozzles, usually at pressures of 7 to 21 megapascals (MPa) (1,000 to 3,000 pounds per square inch). Air-assisted airless spray atomizes the coating by the same mechanism as airless spray, but at lower fluid pressures (under 7 MPa). After atomizing, air is then used to atomize the coating further and to help shape the spray pattern, reducing overspray to levels lower than those achieved with airless atomization alone. Figure 4.2.2.14-4 depicts a typical air-assisted airless spray gun. Air-assisted airless spray has been used to apply prime and color coats but not texture coats, because the larger size of the sprayed coating droplet (relative to that achieved by conventional air atomized spray) makes it difficult to achieve the desired surface finish quality for a texture coat. A touch-up coating step with air atomized equipment is sometimes necessary to apply color to recessed and louvered areas missed by air-assisted airless spray.

In electrostatic air spray, the coating is usually charged electrically, and the parts being coated are grounded to create an electric potential between the coating and the parts. The atomized coating is attracted to the part by electrostatic force. Because plastic is an insulator, it is necessary to provide a conductive surface that can bleed off the electrical charge to maintain the ground potential of the part as the charged coating particles accumulate on the surfaces. Electrostatic air spray has been demonstrated for application of prime and color coats and has been used to apply texture coats,

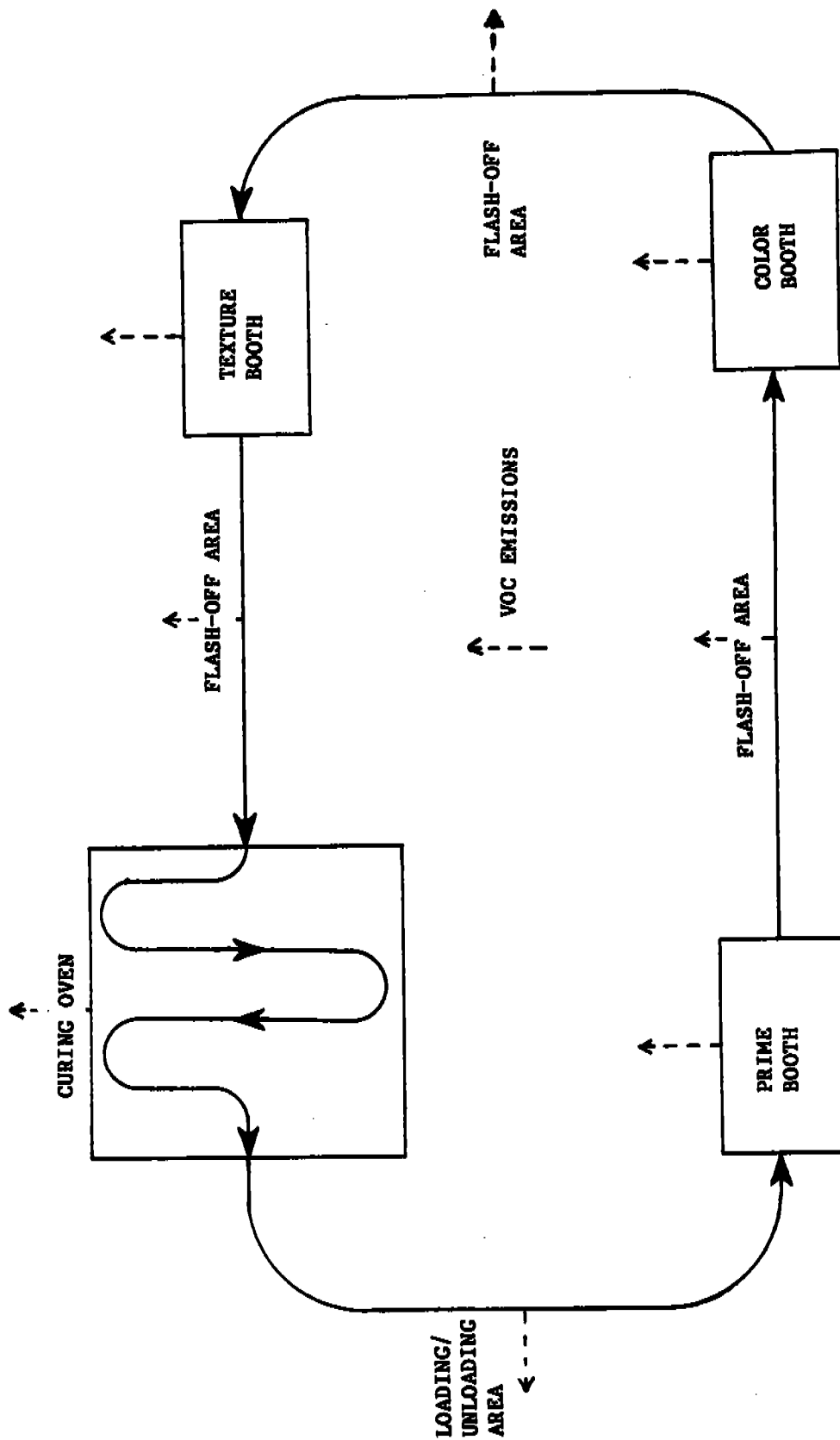


Figure 4.2.2.14-3. Typical conveyor line for three-coat system.

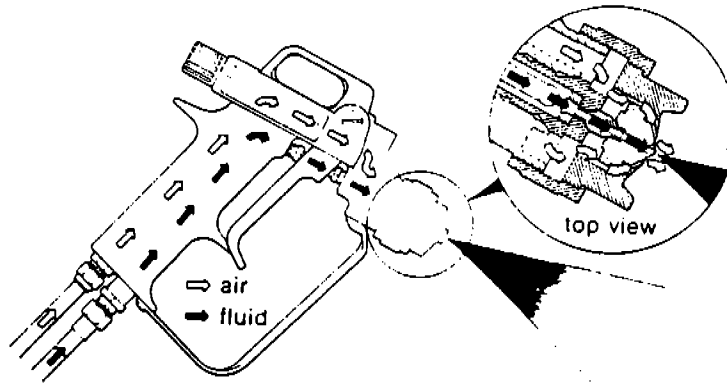


Figure 4.2.2.14-4. Typical air assisted airless spray gun.⁵

but this technique does not function well with the large size particles generated for the texture coat, and it offers no substantial improvement over air atomized spray for texture coating. A touch-up coating step with air atomized spray is sometimes necessary to apply color and texture to recessed and louvered areas missed by electrostatic spray.

The coatings used for decorative/exterior coats are generally solvent-based and waterborne coatings. Solvents used include toluene, methyl ethyl ketone, methylene chloride, xylene, acetone and isopropanol. Typically, organic solvent-based coatings used for decorative/exterior coats are two types of two-component catalyzed urethanes. The solids contents of these coatings are from 30 to 35 volume percent (low solids) and 40 to 54 volume percent (medium solids) at the spray gun (i.e., at the point of application, or as applied). Waterborne decorative/exterior coatings typically contain no more than 37 volume percent solids at the gun. Other decorative/exterior coatings being used by the industry include solvent-based high solids coatings (i.e., equal to or greater than 60 volume percent solids) and one-component low solids and medium solids coatings.

The application of an EMI/RFI shielding coat is done in a variety of ways. About 45 percent of EMI/RFI shielding applied to plastic parts is done by zinc-arc spraying, a process that does not emit volatile organic compounds (VOC). About 45 percent is done using organic solvent-based and waterborne metal-filled coatings, and the remaining EMI/RFI shielding is achieved by a variety of techniques involving electroless plating, and vacuum metallizing or sputtering (defined below), and use of conductive plastics, and metal inserts.

Zinc-arc spraying is a two-step process in which the plastic surface (usually the interior of a housing) is first roughened by sanding or grit blasting and then sprayed with molten zinc. Grit blasting and zinc-arc spraying are performed in separate booths specifically equipped for those activities. Both the surface preparation and the zinc-arc spraying steps currently are performed manually, but robot systems have recently become available. Zinc-arc spraying requires a spray booth, a special spray gun, pressurized air and zinc wire. The zinc-arc spray gun mechanically feeds two zinc wires into the tip of the spray gun, where they are melted by an electric

arc. A high pressure air nozzle blows the molten zinc particles onto the surface of the plastic part. The coating thickness usually ranges from 1 to 4 mils, depending on product requirements.

Conductive coatings can be applied with most conventional spray equipment used to apply exterior coatings. Conductive coatings are usually applied manually with air spray guns, although air-assisted airless spray guns are sometimes used. Electrostatic spray methods can not be used because of the high conductivity of EMI/RFI shielding coatings.

Organic solvent-based conductive coatings contain particles of nickel, silver, copper or graphite, in either an acrylic or an urethane resin. Nickel-filled acrylic coatings are the most frequently used, because of their shielding ability and their lower cost. Nickel-filled acrylics and urethanes contain from 15 to 25 volume percent solids at the gun. Waterborne nickel-filled acrylics with between 25 and 34 volume percent solids at the gun (approximately 50 to 60 volume percent solids, minus water) are less frequently used than are organic-solvent-based conductive coatings.

The application of a conductive coating usually involves three steps: surface preparation, coating application, and curing. Although the first step can be eliminated if parts are kept free of mold-release agents and dirt, part surfaces are usually cleaned by wiping with organic solvents or detergent solutions and then roughened by light sanding. Coatings are usually applied to the interior surface of plastic housings, at a dry film thickness of 1 to 3 mils. Most conductive coatings can be cured at room temperature, but some must be baked in an oven.

Electroless plating is a dip process in which a film of metal is deposited in aqueous solution onto all exposed surfaces of the part. In the case of plastic business machine housings, both sides of a housing are coated. No VOC emissions are associated with the plating process itself. However, coatings applied before the plating step, so that only selected areas of the parts are plated, may emit VOCs. Wastewater treatment may be necessary to treat the spent plating chemicals.

Vacuum metallizing and sputtering are similar techniques in which a thin film of metal (usually aluminum) is deposited from the vapor phase onto the plastic part. Although no VOC emissions occur during the actual metallizing process, prime coats often applied to ensure good adhesion and top coats to protect the metal film may both emit VOCs.

Conductive plastics are thermoplastic resins that contain conductive flakes or fibers of materials such as aluminum, steel, metallized glass or carbon. Resin types currently available with conductive fillers include acrylonitrile butadiene styrene, acrylonitrile butadiene styrene/polycarbonate blends, polyphenylene oxide, nylon 6/6, polyvinyl chloride, and polybutyl terephthalate. The conductivity, and therefore the EMI/RFI shielding effectiveness, of these materials relies on contact or near contact between the conductive particles within the resin matrix. Conductive plastic parts usually are formed by straight injection molding. Structural foam injection molding can reduce the EMI/RFI shield effectiveness of these materials because air pockets in the foam separate the conductive particles.

4.2.2.14.2 Emissions And Controls

The major pollutants from surface coating of plastic parts for business machines are VOC emissions from evaporation of organic solvents in the coatings used, and from reaction byproducts when the coatings cure. VOC sources include spray booth(s), flashoff area(s), and oven(s) or drying areas(s). The relative contribution of each to total VOC emissions from a from plant to plant, but for an average coating operation, about 80 percent is emitted from the spray booth(s), 10 percent from the flashoff area(s), and 10 percent from the oven(s) or drying area(s).

Factors affecting the quantity of VOC emitted are the VOC content of the coatings applied, the solids content of coatings as applied, film build (thickness of the applied coating), and the transfer efficiency (TE) of the application equipment. To determine of VOC emissions when waterborne coatings are used, it is necessary to know the amounts of VOC, water and solids in the coatings.

The TE is the fraction of the solids sprayed that remains on a part. TE varies with application technique and with type of coating applied. Table 4.2.2.14-1 presents typical TE values for various application methods.

TABLE 4.2.2.14-1. TRANSFER EFFICIENCIES*

Application methods	Transfer efficiency (%)	Type of coating
Air atomized spray	25	Prime, color, texture, touchup and fog coats
Air-assisted airless spray	40	Prime, color coats
Electrostatic air spray	40	Prime, color coats

*As noted in the promulgated standards, values are presented solely to aid in determining compliance with the standards and may not reflect actual TE at a given plant. For this reason, table should be used with caution for estimating VOC emissions from any new facility. For a more exact estimate of emissions, the actual TE from specific coating operations at a given plant should be used.¹

Volatile organic compound emissions can be reduced by using low VOC-content coatings (i.e., high solids or waterborne coatings), using surface finishing techniques that do not emit VOC, improved TE, and/or added controls. Lower VOC content decorative/exterior coatings include high solids-content (i.e., at least 60 volume percent solids at the spray gun) two-component catalyzed urethane coatings and waterborne coatings (i.e., 37 volume percent solids and 12.6 volume percent VOC at the spray gun). Both of these types of exterior/decorative coatings contain less VOC than conventional urethane

TABLE 4.2.2.14-2. REPRESENTATIVE PARAMETERS FOR SURFACE COATING OPERATIONS TO APPLY DECORATIVE/EXTERIOR COATINGS^a

Plant size	Operating schedule (h/yr)	Number of spray booths Dry filter Water wash	Surface area coated/yr (m ² of plastic)	Coating option/ control technique	Coating sprayed (L/yr)
Small	4,000	2	9,711	Baseline coating mix ^b	16,077 ^c
				Low solids SB coating ^d	18,500 ^c
				Medium solids SB coating ^e	11,840 ^c
				High solids SB coating ^f	9,867 ^c / 6,167 ^g
				WB coating ^h	16,000 ^c
Medium	4,000	5 ⁱ	77,743	Baseline coating mix ^b	128,704 ^c
				Low solids SB coating ^d	148,100 ^c
				Medium solids SB coating ^e	94,784 ^c
				High solids SB coating ^f	78,987 ^c / 49,367 ^g
				WB coating ^h	128,086 ^c
Large	4,000	6 ^j	194,370	Baseline coating mix ^b	321,760 ^c
				Low solids SB coating ^d	370,275 ^c
				Medium solids SB coating ^e	236,976 ^c
				High solids SB coating ^f	197,480 ^c / 123,425 ^g
				WB coating ^h	320,238 ^c

^aDoes not address EMI/RFI shielding coatings. SB = solventborne. WB = waterborne.

^bAssumes baseline decorative/exterior coating consumption consists of a mix of coatings as follows:

64.8% = Solvent base two-component catalyzed urethane containing 32 volume % solids at the gun.

23.5% = Solvent base two-component catalyzed urethane containing 50 volume % solids at the gun.

11.7% = Waterborne acrylic containing 37 volume % solids and 12.6 volume % organic solvent at the gun.

^cAssumes 25% transfer efficiency (TE) based on the use of air atomized spray equipment.

TABLE 4.2.2.14-2 (cont.)

- d Assumes use of a solvent base coating containing 32 volume % solids at the gun.
- e Assumes use of a solvent base coating containing 50 volume % solids at the gun.
- f Assumes the use of a solvent base two-component catalyzed urethane coating containing 60 volume % solids at the gun.
- g Assumes 40% TE based on the use of air assisted airless spray equipment, as required by new source performance standards.
- h Assumes the use of a waterborne coating containing 37 volume % solids and 12.6 volume % organic solvent at the gun.
- i Assumes two spray booths are for batch surface coating operations and remaining three booths are on a conveyor line.
- j Assumes two spray booths are for batch surface coating operations and remaining four booths are on a conveyor line.
- k Assumes that three spray booths are on a conveyor line.

TABLE 4.2.2.14-3. REPRESENTATIVE PARAMETERS FOR SURFACE COATING OPERATIONS TO APPLY EMI/RFI SHIELDING COATINGS^a

Plant size	Operating schedule (h/yr)	Number of spray booths		Surface area coated/yr (m ² of plastic)	Coating option/control technique	Coating sprayed (ℓ/yr) ^b
Small	4,000	0	0	4,921	Low solids SB EMI/RFI shielding coating ^{c,d}	3,334
					Higher solids SB EMI/RFI shielding coating ^{e,d}	2,000
					WB EMI/RFI shielding coating ^{f,d}	1,515
Medium	4,000	2	2	109,862	Zinc arc spray ^{g-i}	750
					Low solids SB EMI/RFI shielding coating ^{c,d}	74,414
					Higher solids SB EMI/RFI shielding coating ^{e,d}	44,648
Large	4,000	4	4	239,239	WB EMI/RFI shielding coating ^{f,d}	33,824
					Zinc arc spray ^{g-i}	16,744
					Low solids SB EMI/RFI shielding coating ^{c,d}	162,040
					Higher solids SB EMI/RFI shielding coating ^{e,d}	97,224
					WB EMI/RFI shielding coating ^{f,d}	73,554
					Zinc arc spray ^{g-i}	34,460

TABLE 4.2.2.14-3 (cont.)

- ^aIncludes sprayed conductive coatings using the dry filter and water wash spray booths listed in Table 4.2.2.14-2. SB = solventborne. WB = waterborne.
- ^bAssumes 50% transfer efficiency (TE).
- ^cAssumes use of a solvent base EMI/RFI shielding coating containing 15 volume % solids at the gun.
- ^dApplied at a 2 mil thickness (standard industry practice).
- ^eAssumes use of a solvent base EMI/RFI shielding coating containing 25 volume % solids at the gun.
- ^fAssumes use of a waterborne EMI/RFI shielding coating containing 33 volume % solids and 18.8 volume % organic solvent at the gun.
- ^gAssumes use of zinc-arc spray shielding.
- ^hApplied at a 3 mil thickness (standard industry practice).
- ⁱBased on amount of zinc wire sprayed per year (kg/yr) and zinc density of 6.32 g/ml.

TABLE 4.2.2.14-4. EMISSION FACTORS FOR VOC FROM SURFACE COATING OPERATIONS TO APPLY DECORATIVE/EXTERIOR COATINGS^{a, b}

Plant configuration and control technique	kg/m ² coated	Volatile organics	
		kg/yr	kg/hr
Small			
Baseline coating mix ^c	0.84	8,122	2.0
Low solids SB coating ^d	1.14	11,096	2.8
Medium solids SB coating ^e	0.54	5,221	1.3
High solids SB coating ^f	0.36/0.22	3,481/2,176	0.87/0.54
WB Coating ^g	0.18	1,778	0.44
Medium			
Baseline coating mix ^c	0.84	64,986	16.2
Low solids SB coating ^d	1.14	88,825	22.2
Medium solids SB coating ^e	0.54	41,800	10.4
High solids SB coating ^f	0.36/0.22	27,867/17,417	7.0/4.4
WB Coating ^g	0.18	14,234	3.6
Large			
Baseline coating mix ^c	0.84	162,463	40.6
Low solids SB coating ^d	1.14	222,076	55.5
Medium solids SB coating ^e	0.54	104,506	26.1
High solids SB coating ^f	0.36/0.22	69,671/43,544	17.4/10.9
WB Coating ^g	0.18	35,589	8.9

TABLE 4.2.2.14-4 (cont.)

^aAssumes values given in Table 4.2.2.14-2, using the following equation: $E = LDV$.

where:

E = VOC emission factors from surface coating operations (kg/yr)
 L = Volume of coating sprayed (ℓ)
 D = Density of coating sprayed (kg/ ℓ)
 V = Volatile content of coating, including dilution solvents added at plant (weight fraction).

^bAssumes all VOC present is emitted. Values have been rounded off. Does not address EMI/BFI shielding coatings. Assumes annual operating schedule of 4,000 hours. SB = solventborne. WB = waterborne.

^cBased on use of the baseline coating mix in Table 4.2.2.14-2.

^dBased on use of a solvent base coating containing 32 volume % solids at the gun.

^eBased on use of a solvent base coating containing 50 volume % solids at the gun.

^fBased on use of a solvent base coating containing 60 volume % solids at the gun.

^gBased on use of a waterborne coating containing 37 volume % solids and 12.6 volume % organic solvent at the gun.

TABLE 4.2.2.14-5. EMISSION FACTORS FOR VOC FROM SURFACE COATING OPERATIONS TO APPLY EMI/RFI SHIELDING COATINGS^{a,b}

Plant configuration and control technique	kg/m ² coated	Volatile organics	
		kg/yr	kg/hr
Small			
Low Solids SB EMI/RFI shielding coating ^c	0.51	2,500	0.62
Higher solids SB EMI/RFI shielding coating ^d	0.27	1,323	0.33
WB EMI/RFI shielding coating ^e	0.05	251	0.063
Zinc-arc spray ^f	0	0	0
Medium			
Low solids SB EMI/RFI shielding coating ^c	0.51	55,787	13.9
Higher solids SB EMI/RFI shielding coating ^d	0.27	29,535	7.4
WB EMI/RFI shielding coating ^e	0.05	5,609	1.4
Zinc-arc spray ^f	0	0	0
Large			
Low solids SB EMI/RFI shielding coating ^c	0.51	121,484	30.4
Higher solids SB EMI/RFI shielding coating ^d	0.27	64,314	16.1
WB EMI/RFI shielding coating ^e	0.05	12,214	3.1
Zinc-arc spray ^f	0	0	0

TABLE 4.2.2.14-5 (cont.)

^a Assumes values given in Table 4.2.2.14-3, using the following equation: $E = LDW$

Where:

E = VOC emission factors from EMI/RFI shielding coating operations (kg/yr)
 L = Volume of coating sprayed (ℓ)
 D = Density of coating sprayed (kg/ℓ)
 V = Volatile content of coating, including dilution solvents added at plant (fraction by weight).

^b Assumes all VOC present is emitted. Values have been rounded off. Does not address EMI/RFI shielding coatings. Assumes annual operating schedule of 4,000 hours. SB = solventborne. WB = waterborne.
^c Assumes use of a solvent base EMI/RFI shielding coating containing 15 volume % solids at the gun.
^d Assumes use of a solvent base EMI/RFI shielding coating containing 25 volume % solids at the gun.
^e Assumes use of a waterborne EMI/RFI shielding coating containing 33 volume % solids and 18.8 volume % organic solvent at the gun.
^f Assumes use of a zinc-arc spray shielding.

coatings, which are typically 32 volume percent solids at the gun. Lower VOC content EMI/RFI shielding coatings include organic solvent-based acrylic or urethane conductive coatings containing at least 25 volume percent solids at the spray gun and waterborne conductive coatings containing 30 to 34 volume percent solids at the gun. Use of lower VOC content coatings reduces emissions of VOCs both by reducing the volume of coating needed to cover the part(s) and by reducing the amount of VOC in the coatings that are sprayed.

The major technique which provides an attractive exterior/decorative finish on plastic parts for business machines without emitting VOCs is the use of molded-in color and texture. VOC-free techniques for EMI/RFI shielding include zinc-arc spraying, electroless plating, the use of conductive plastics or metal inserts, and in some cases, vacuum metallizing and sputtering.

Transfer efficiency can be improved by using air-assisted airless or electrostatic spray equipment, which are more efficient than the common application technique (air atomized). More efficient equipment can reduce VOC emissions by as much as 37 percent over conventional air atomized spray equipment, through reducing the amount of coating that must be sprayed to achieve a given film thickness.

Addon controls applied to VOC emissions in other surface coating industries include thermal and catalytic incinerators, carbon adsorbers and condensers. However, these control technologies have not been used in the surface coating of plastic parts because the large volume of exhaust air and the low concentrations of VOC in the exhaust reduce their efficiency.

The operating parameters in Tables 4.2.2.14-2 and 4.2.2.14-3 and the emissions factors in Tables 4.2.2.14-4 and 4.2.2.14-5 are representative of conditions at existing plants with similar operating characteristics. The three general sizes of surface coating plants presented in these tables (small, medium and large) are given to assist in making a general estimate of VOC emissions. However, each plant has its own combination of coating formulations, application equipment and operating parameters. Thus, it is recommended that, whenever possible, plant-specific values be obtained for all variables when calculating emission estimates.

A material balance may be used to provide a more accurate estimate of VOC emissions from the surface coating of plastic parts for business machines. An emissions estimate can be calculated using coating composition data (as determined by EPA Reference Method 24) and data on coating and solvent quantities used in a given time period by a surface coating operation. Using this approach, emissions are calculated as follows:

$$M_T = \sum_{i=1}^n L_{ci} D_{ci} W_{oi}$$

where:

M_T = total mass of VOC emitted (kg)

L_c = volume of each coating consumed, as sprayed (ℓ)

D_c = density of each coating as sprayed (k/ℓ)

W_i = the proportion of VOC in each coating, as sprayed (including dilution solvent added at plant) (weight fraction)
 n = number of coatings applied.

References for Section 4.2.2.14

1. Surface Coating Of Plastic Parts For Business Machines - Background Information for Proposed Standards, EPA-450/3-85-019a, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1985.
2. Written communication from Midwest Research Institute, Raleigh, NC, to David Salzman, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 19, 1985.
3. Protectaire[®] Spray Booths, Protectaire Systems Company, Elgin, IL, 1982.
4. Binks[®] Spray Booths and Related Equipment, Catalog SB-7, Binks Manufacturing Company, Franklin Park, IL, 1982.
5. Product Literature on Wagner[®] Air Coat[®] Spray Gun, Wagner Spray Technology, Minneapolis, MN, 1982.

5.19 SYNTHETIC FIBER MANUFACTURING

5.19.1 General¹⁻³

There are two types of synthetic fiber products, the semisynthetics, or cellulosics, (viscose rayon and cellulose acetate) and the true synthetics, or noncellulosics, (polyester, nylon, acrylic and modacrylic, and polyolefin). These six fiber types compose over 99 percent of the total production of manmade fibers in the U. S.

5.19.2 Process Description²⁻⁶

Semisynthetics are formed from natural polymeric materials such as cellulose. True synthetics are products of the polymerization of smaller chemical units into long chain molecular polymers. Fibers are formed by forcing a viscous fluid or solution of the polymer through the small orifices of a spinneret (see Figure 5.19-1) and immediately solidifying or precipitating the resulting filaments. This prepared polymer may also be used in the manufacture of other than fiber products, such as the enormous number of extruded plastic and synthetic rubber products.

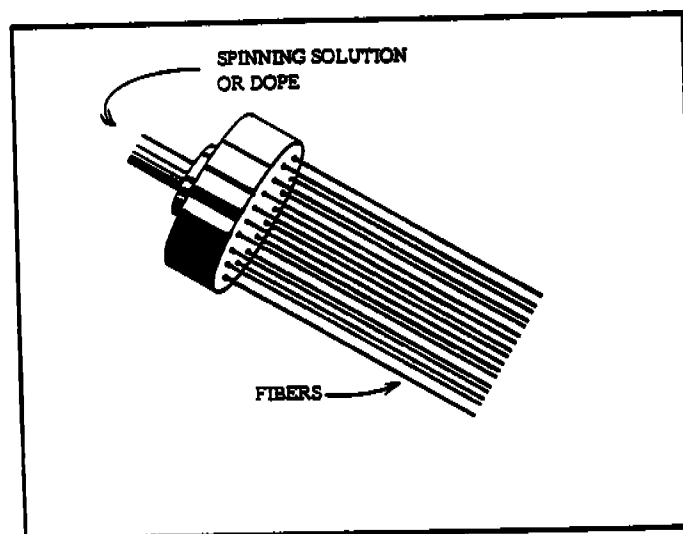


Figure 5.19-1. Spinneret.

Synthetic fibers (both semisynthetic and true synthetic) are produced typically by two easily distinguishable methods, melt spinning and solvent spinning. Melt spinning processes use heat to melt the fiber polymer to a viscosity suitable for extrusion through the spinneret. Solvent spinning processes use large amounts of organic solvents, which usually are recovered for economic reasons, to dissolve the fiber polymer into a fluid polymer solution suitable for extrusion through a spinneret. The major solvent spinning operations are dry spinning and wet spinning. A third method,

reaction spinning, is also used, but to a much lesser extent. Reaction spinning processes involve the formation of filaments from prepolymers and monomers that are further polymerized and cross linked after the filament is formed.

Figure 5.19-2 is a general process diagram for synthetic fiber production using the major types of fiber spinning procedures. The spinning process used for a particular polymer is determined by the polymer's melting point, melt stability and solubility in organic and/or inorganic (salt) solvents. (The polymerization of the fiber polymer is typically carried out at the same facility that produces the fiber.) Table 5.19-1 lists the different types of spinning methods with the fiber types produced by each method. After the fiber is spun, it may undergo one or more different processing treatments to meet the required physical or handling properties. Such processing treatments include drawing, lubrication, crimping, heat setting, cutting, and twisting. The finished fiber product may be classified as tow, staple, or continuous filament yarn.

TABLE 5.19-1. TYPES OF SPINNING METHODS AND
FIBER TYPES PRODUCED

Spinning method	Fiber type
Melt spinning	Polyester Nylon 6 Nylon 66 Polyolefin
Solvent spinning	
Dry solvent spinning	Cellulose acetate Cellulose triacetate Acrylic Modacrylic Vinyon Spandex
Wet solvent spinning	Acrylic Modacrylic
Reaction spinning	Spandex Rayon (viscose process)

Melt Spinning - Melt spinning uses heat to melt the polymer to a viscosity suitable for extrusion. This type of spinning is used for polymers that are not decomposed or degraded by the temperatures necessary for extrusion. Polymer chips may be melted by a number of methods. The trend is toward melting and immediate extrusion of the polymer chips in an electrically heated screw extruder. Alternatively, the molten polymer is processed in an inert gas atmosphere, usually nitrogen, and is metered through a precisely machined gear pump to a filter assembly consisting of a series of metal gauges interspersed in layers of graded sand. The molten polymer is extruded at high

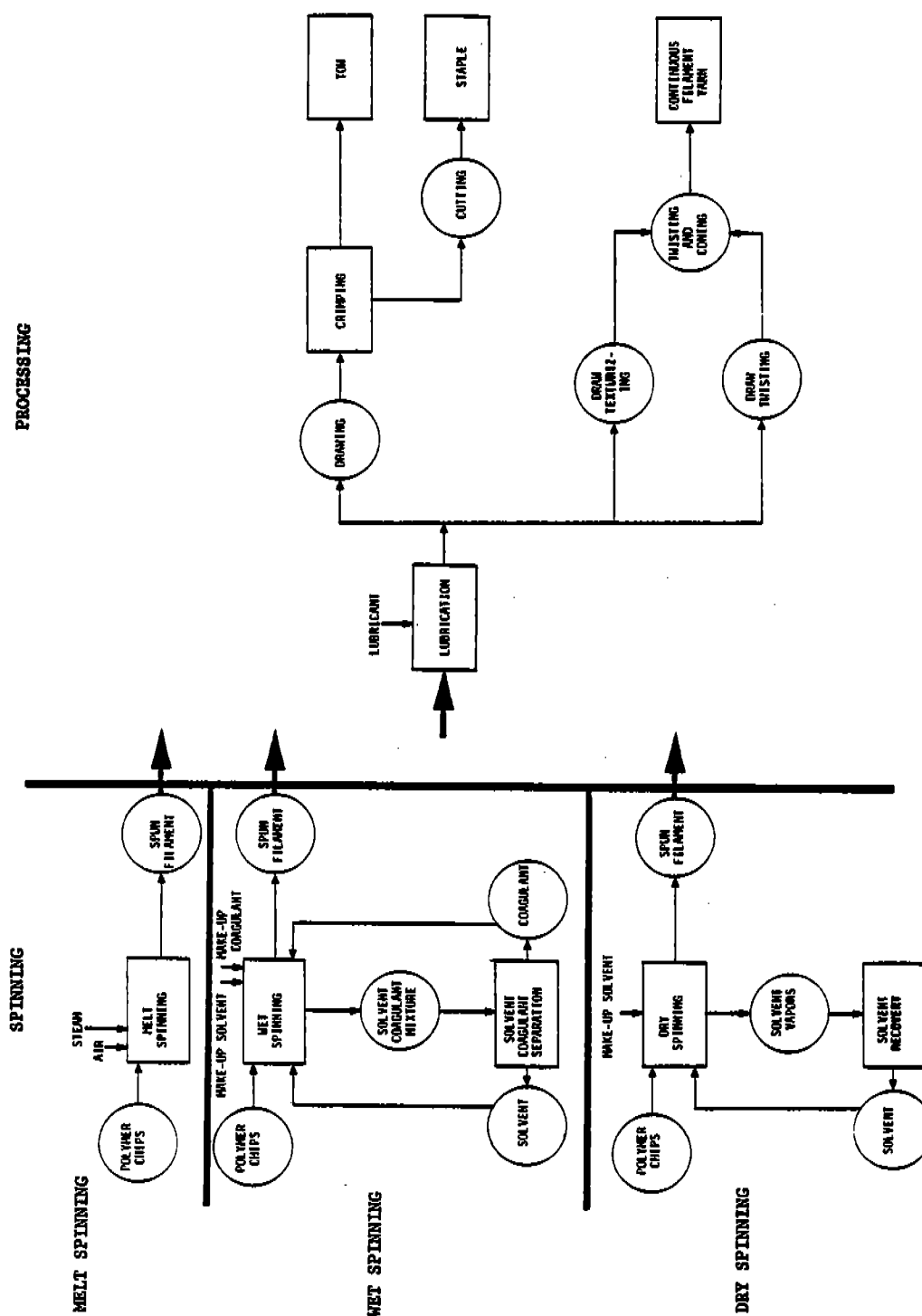


Figure 5.19-2. General process diagram for melt, wet and dry spun synthetic fibers.

pressure and constant rate through a spinneret into a relatively cooler air stream which solidifies the filaments. Lubricants and finishing oils are applied to the fibers in the spin cell. At the base of the spin cell, a thread guide converges the individual filaments to produce a continuous filament yarn, or a spun yarn, that typically is composed of between 15 and 100 filaments. Once formed, the filament yarn either is immediately wound onto bobbins or is further treated for certain desired characteristics or end use. Treatments include drawing, lubrication, crimping, heat setting, cutting, and twisting.

Since melt spinning does not require the use of solvents, VOC emissions are significantly lower than those from dry and wet solvent spinning processes. Lubricants and oils are sometimes added during the spinning of the fibers to provide certain properties necessary for subsequent operations, such as lubrication and static suppression. These lubricants and oils vaporize, condense, and then coalesce as aerosols primarily from the spinning operation, although certain post-spinning operations may also give rise to these aerosol emissions.

Dry Solvent Spinning - The dry spinning process begins by dissolving the polymer in an organic solvent. This solution is blended with additives and is filtered to produce a viscous polymer solution, referred to as "dope", for spinning. The polymer solution is then extruded through a spinneret as filaments into a zone of heated gas or vapor. The solvent evaporates into the gas stream and leaves solidified filaments, which are further treated using one or more of the processes described in the general process description section. (See Figure 5.19-3.) This type of spinning is used for easily dissolved polymers such as cellulose acetate, acrylics and modacrylics.

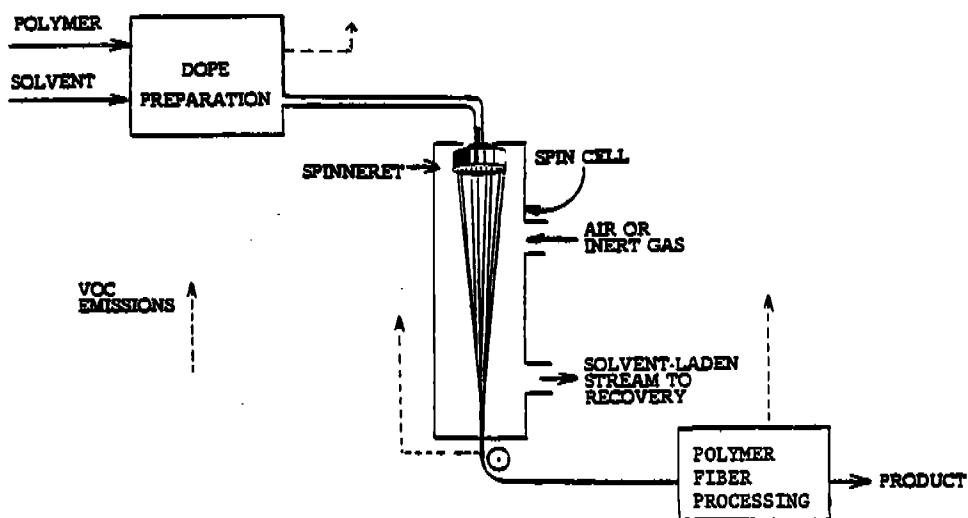


Figure 5.19-3. Dry spinning.

Dry spinning is the fiber formation process potentially emitting the largest amounts of VOC per pound of fiber produced. Air pollutant emissions include volatilized residual monomer, organic solvents, additives, and other organic compounds used in fiber processing. Unrecovered solvent constitutes the major substance. The largest amounts of unrecovered solvent are emitted from the fiber spinning step and drying the fiber. Other emission sources include dope preparation (dissolving the polymer, blending the spinning solution, and filtering the dope), fiber processing (drawing, washing, crimping) and solvent recovery.

Wet Solvent Spinning - Wet spinning also uses solvent to dissolve the polymer to prepare the spinning dope. The process begins by dissolving polymer chips in a suitable organic solvent, such as dimethylformamide (DMF), dimethylacetamide (DMAc), or acetone, as in dry spinning; or in a weak inorganic acid, such as zinc chloride or aqueous sodium thiocyanate. In wet spinning, the spinning solution is extruded through spinnerets into a precipitation bath that contains a coagulant (or precipitant) such as aqueous DMAc or water. Precipitation or coagulation occurs by diffusion of the solvent out of the thread and by diffusion of the coagulant into the thread. Wet spun filaments also undergo one or more of the additional treatment processes described earlier, as depicted in Figure 5.19-4.

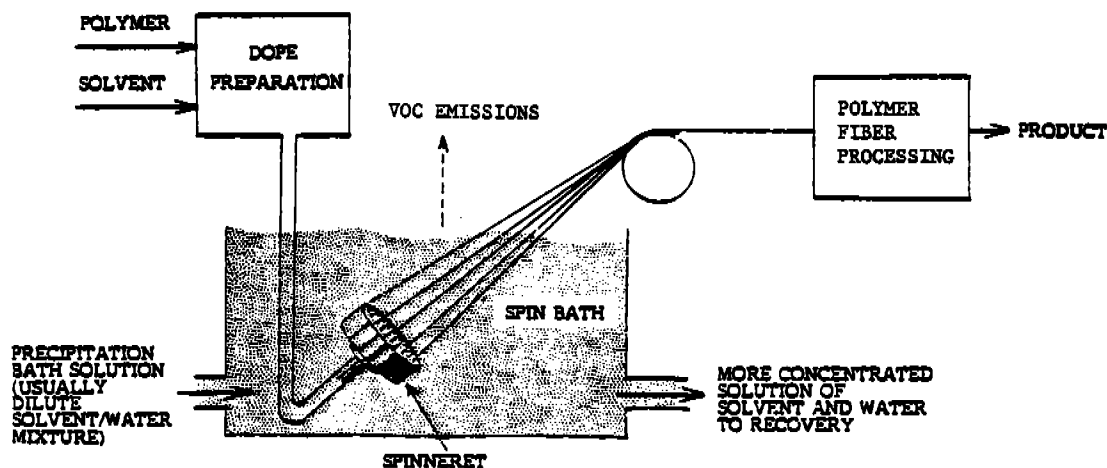


Figure 5.19-4. Wet spinning.

Air pollution emission points in the wet spinning organic solvent process are similar to those of dry spinning. Wet spinning processes that use solutions of acids or salts to dissolve the polymer chips emit no solvent VOC, only unreacted monomer, and are, therefore, relatively clean from an air pollution standpoint. For those that require solvent, emissions occur as solvent evaporates from the spinning bath and from the fiber in post-spinning operations.

Reaction Spinning - As in the wet and dry spinning processes, the reaction spinning process begins with the preparation of a viscous spinning solution, which is prepared by dissolving a low molecular weight polymer, such as polyester for the production of spandex fibers, in a suitable solvent and a reactant, such as di-isocyanate. The spinning solution is then forced through spinnerets into a solution containing a diamine, similarly to wet spinning, or is combined with the third reactant and then dry spun. The primary distinguishable characteristic of reaction spinning processes is that the final cross-linking between the polymer molecule chains in the filament occurs after the fibers have been spun. Post-spinning steps typically include drying and lubrication. Emissions from the wet and dry reaction spinning processes are similar to those of solvent wet and dry spinning, respectively.

5.19.3 Emissions And Controls

For each pound of fiber produced with the organic solvent spinning processes, a pound of polymer is dissolved in about 3 pounds of solvent. Because of the economic value of the large amounts of solvent used, capture and recovery of these solvents are an integral portion of the solvent spinning processes. At present, 94 to 98 percent of the solvents used in these fiber formation processes is recovered. In both dry and wet spinning processes, capture systems with subsequent solvent recovery are applied most frequently to the fiber spinning operation alone, because the emission stream from the spinning operation contains the highest concentration of solvent and, therefore, possesses the greatest potential for efficient and economic solvent recovery. Recovery systems used include gas adsorption, gas absorption, condensation, and distillation and are specific to a particular fiber type or spinning method. For example, distillation is typical in wet spinning processes to recover solvent from the spinning bath, drawing, and washing (see Figure 5.19-8), while condensers or scrubbers are typical in dry spinning processes for recovering solvent from the spin cell (see Figures 5.19-6 and 5.19-9). The recovery systems themselves are also a source of emissions from the spinning processes.

The majority of VOC emissions from pre-spinning (dope preparation, for example) and post-spinning (washing, drawing, crimping, etc.) operations typically are not recovered for reuse. In many instances, emissions from these operations are captured by hoods or complete enclosures to prevent worker exposure to solvent vapors and unreacted monomer. Although already captured, the quantities of solvent released from these operations are typically much smaller than those released during the spinning operation. The relatively high air flow rates required in order to reduce solvent and monomer concentrations around the process line to acceptable health and safety limits make recovery economically unattractive. Solvent recovery, therefore, is usually not attempted.

Table 5.19-2 presents emission factors from production of the most widely known semisynthetic and true synthetic fibers. These emission factors address emissions only from the spinning and post-spinning operations and the associated recovery or control systems. Emissions from the polymerization of the fiber polymer and from the preparation of the fiber polymer for spinning are not included in these emission factors. While significant emissions occur in the polymerization and related processes, these emissions are discussed in Sections 5.13, "Plastics", and 5.20, "Synthetic Rubber".

TABLE 5.19-2. EMISSION FACTORS FOR SYNTHETIC FIBER MANUFACTURING
EMISSION FACTOR RATING: C

Type of Fiber	Nonmethane Volatile Organics	Particulate	References
Rayon, viscose process	0	c	7-8,10,35-36
Cellulose acetate, filter tow	112 ^d	c	11,37
Cellulose acetate and triacetate, filament yarn	199 ^{d,e}	c	11,38
Polyester, melt spun			41-42
Staple	0.6 ^{f,g}	25.2 ^{h,j}	
Yarn ^k	0.05 ^{f,g}	0.03 ^{g,j}	
Acrylic, dry spun			21,43-44
Uncontrolled	40	c	
Controlled	32 ^m	c	
Modacrylic, dry spun	125 ^{g,h}	c	45
Acrylic and modacrylic, wet spun	6.75 ^p	c	19,46
Acrylic, inorganic wet spun			47-48
Homopolymer	20.7 ^{g,q}	c	
Copolymer	2.75 ^{g,r}	c	
Nylon 6, melt spun			25,49
Staple	3.93 ^g	0.01 ^g	
Yarn	0.45 ^s	c	
Nylon 66, melt spun			26
Uncontrolled	2.13 ^{f,t}	0.5 ^u	
Controlled	0.31 ^{f,v}	0.1 ^u	
Polyolefin, melt spun	5 ^g	0.01 ^g	5,25,28,49
Spandex, dry spun	4.23 ^m	c	32
Spandex, reaction spun	138 ^x	c	50-51
Vinyon, dry spun	150 ^m	c	52

^aFactors are pounds of emissions per 1000 pounds of fiber spun, including waste fiber.

^bUncontrolled carbon disulfide (CS₂) emissions are 251 lb CS₂/1000 lb fiber spun; uncontrolled hydrogen sulfide emissions are 50.4 lb H₂S/1000 lb fiber

TABLE 5.19-2 (CONT.).

- spun. If recovery of CS₂ from the "hot dip" stage takes place, CS₂ emissions are reduced by about 16%.
- ^cParticulate emissions from the spinning solution preparation area and later stages through the finished product are essentially nil.
- ^dAfter recovery from the spin cells and dryers. Use of more extensive recovery systems can reduce emissions by 40% or more.
- ^eUse of methyl chloride and methanol as the solvent, rather than acetone, in production of triacetate can double emissions.
- ^fEmitted in aerosol form.
- ^gUncontrolled.
- ^hAfter control on extrusion parts cleaning operations.
- ^jMostly particulate, with some aerosols.
- ^kFactors for high intrinsic viscosity industrial and tire yarn production are 0.18 lb VOC and 3.85 lb particulate.
- ^mAfter recovery from spin cells.
- ⁿAbout 18 lb is from dope preparation, and about 107 lb is from spinning/post-spinning operations.
- ^pAfter solvent recovery from the spinning, washing, and drawing stages. This factor includes acrylonitrile emissions. An emission factor of 87 lb/1000 lb fiber has been reported.
- ^qAverage emission factor; range is from 13.9 to 27.7 lb.
- ^rAverage emission factor; range is from 2.04 to 16.4 lb.
- ^sAfter recovery of emissions from the spin cells. Without recovery, emission factor would be 1.39 lb.
- ^tAverage of plants producing yarn from batch and continuous polymerization processes. Range is from about 0.5 to 4.9 lb. Add 0.1 lb to the average factor for plants producing tow or staple. Continuous polymerization processes average emission rates approximately 170%. Batch polymerization processes average emission rates approximately 80%.
- ^uFor plants with spinning equipment cleaning operations.
- ^vAfter control of spin cells in plants with batch and continuous polymerization processes producing yarn. Range is from 0.1 to 0.6 lb. Add 0.02 lb to the average controlled factor for producing tow or staple. Double the average controlled emission factor for plants using continuous polymerization only; subtract 0.01 lb for plants using batch polymerization only.
- ^wAfter control of spinning equipment cleaning operation.
- ^xAfter recovery by carbon adsorption from spin cells and post-spinning operations. Average collection efficiency 83%. Collection efficiency of carbon adsorber decreases over 18 months from 95% to 63%.

Examination of VOC pollutant emissions from the synthetic fibers industry has recently concentrated on those fiber production processes that use an organic solvent to dissolve the polymer for extrusion or that use an organic solvent in some other way during the filament forming step. Such processes, while representing only about 20 percent of total industry production, do generate about 94 percent of total industry VOC emissions. Particulate emissions from fiber plants are relatively low, at least an order of magnitude lower than the solvent VOC emissions.

5.19.4 Semisynthetics

Rayon Fiber Process Description^{5,7-10} - In the United States, most rayon is made by the viscose process. Rayon fibers are made using cellulose (dissolved wood pulp), sodium hydroxide, carbon disulfide, and sulfuric acid. As shown in Figure 5.19-5, the series of chemical reactions in the viscose process used to make rayon consists of the following stages:

1. Wood cellulose and a concentrated solution of sodium hydroxide react to form soda cellulose.
2. The soda cellulose reacts with carbon disulfide to form sodium cellulose xanthate.
3. The sodium cellulose xanthate is dissolved in a dilute solution of sodium hydroxide to give a viscose solution.
4. The solution is ripened or aged to complete the reaction.
5. The viscose solution is extruded through spinnerets into dilute sulfuric acid, which regenerates the cellulose in the form of continuous filaments.

Emissions And Controls - Air pollutant emissions from viscose rayon fiber production are mainly carbon disulfide (CS_2), hydrogen sulfide (H_2S), and small amounts of particulate matter. Most CS_2 and H_2S emissions occur during the spinning and post-spinning processing operations. Emission controls are not used extensively in the rayon fiber industry. A counter-current scrubber (condenser) is used in at least one instance to recover CS_2 vapors from the sulfuric acid bath alone. The emissions from this operation are high enough in concentration and low enough in volume to make such recovery both technically and economically feasible. The scrubber recovers nearly all of the CS_2 and H_2S that enters it, reducing overall CS_2 and H_2S emissions from the process line by about 14 percent. While carbon adsorption systems are capable of CS_2 emission reductions of up to 95 percent, attempts to use carbon adsorbers have had serious problems.

Cellulose Acetate And Triacetate Fiber Process Description^{5,11-14} - All cellulose acetate and triacetate fibers are produced by dry spinning. These fibers are used for either cigarette filter tow or filament yarn. Figure 5.19-6 shows the typical process for the production of cigarette filter tow. Dried cellulose acetate polymer flakes are dissolved in a solvent, acetone and/or a chlorinated hydrocarbon in a closed mixer. The spinning solution (dope) is filtered, as it is with other fibers. The dope is forced through spinnerets to form cellulose acetate filaments, from which the solvent rapidly

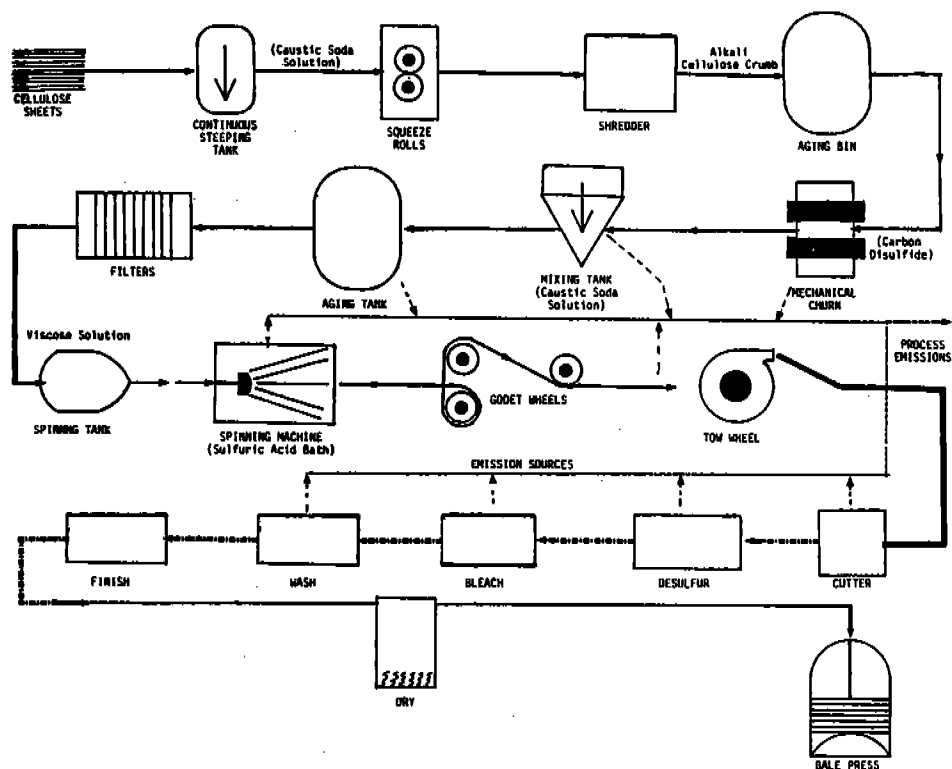


Figure 5.19-5. Rayon viscose process.

evaporates as the filaments pass down a spin cell or column. After the filaments emerge from the spin cell, there is a residual solvent content which continues to evaporate more slowly until equilibrium is attained. The filaments then undergo several post-spinning operations before they are cut and baled.

In the production of filament yarn, the same basic process steps are carried out as for filter tow, up through and including the actual spinning of the fiber. Unlike filter tow filaments, however, filaments used for filament yarn do not undergo the series of post-spinning operations shown in Figure 5.19-6, but rather are wound immediately onto bobbins as they emerge from the spin cells. In some instances, a slight twist is given to the filaments to meet product specifications. In another area, the wound filament yarn is subsequently removed from the bobbins and wrapped on beams or cones (referred to as "beaming") for shipment.

Emissions And Controls - Air pollutant emissions from cellulose acetate fiber production include solvents, additives and other organic compounds used in fiber processing. Acetone, methyl ethyl ketone and methanol are the only solvents currently used in commercial production of cellulose acetate and triacetate fibers.

In the production of all cellulose acetate fibers, i.e., tow, staple, or filament yarn, solvent emissions occur during dissolving of the acetate flakes, blending and filtering of the dope, spinning of the fiber, processing of the fiber after spinning, and the solvent recovery process. The largest emissions of solvent occur during spinning and processing of the fiber. Filament yarns are typically not dried as thoroughly in the spinning cell as are tow or staple yarns. Consequently, they contain larger amounts of residual solvent, which evaporates into the spinning room air where the filaments are

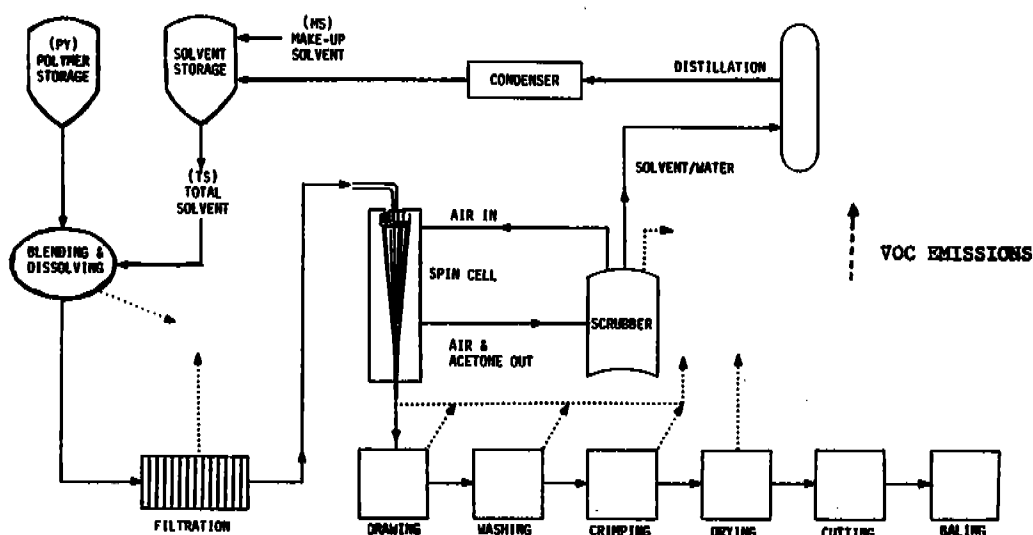


Figure 5.19-6. Cellulose acetate and triacetate filter tow.

wound and into the room air where the wound yarn is subsequently transferred to beams. This residual solvent continues to evaporate for several days, until an equilibrium is attained. The largest emissions occur during the spinning of the fiber and the evaporation of the residual solvent from the wound and beamed filaments. Both processes also emit lubricants (various vegetable and mineral oils) applied to the fiber after spinning and before winding, particularly from the dryers in the cigarette filter tow process.

VOC control techniques are primarily carbon adsorbers and scrubbers. They are used to control and recover solvent emissions from process gas streams from the spin cells in both the production of cigarette filter tow and filament yarn. Carbon adsorbers also are used to control and recover solvent emissions from the dryers used in the production of cigarette filter tow. The solvent recovery efficiencies of these recovery systems range from 92 to 95 percent. Fugitive emissions from other post-spinning operations, even though they are a major source, are generally not controlled. In at least one instance however, an air management system is being used in which the air from the dope preparation and beaming areas is combined at carefully controlled rates with the spinning room air which is used to provide the quench air for the spin cell. A fixed amount of spinning room air is then combined with the process gas stream from the spin cell and this mix is vented to the recovery system.

5.19.5 True Synthetic Fibers

Polyester Fiber Process Description^{5,11,15-17} - Polyethylene terephthalate (PET) polymer is produced from ethylene glycol and either dimethyl terephthalate (DMT) or terephthalic acid (TPA). Polyester filament yarn and staple are manufactured either by direct melt spinning of molten PET from the polymerization equipment or by spinning reheated polymer chips. Polyester fiber spinning is done almost exclusively with extruders, which feed

the molten polymer under pressure through the spinnerets. Filament solidification is induced by blowing the filaments with cold air at the top of the spin cell. The filaments are then led down the spin cell through a fiber finishing application, from which they are gathered into tow, hauled off and coiled into spinning cans. The post-spinning processes, steps 14 through 24 in Figure 5.19-7, usually take up more time and space and may be located far from the spinning machines. Depending on the desired product, post-spinning operations vary but may include lubrication, drawing, crimping, heat setting, and stapling.

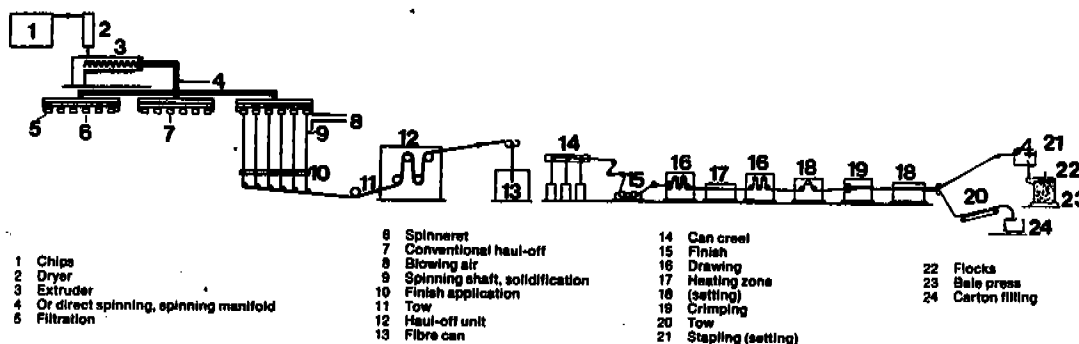


Figure 5.19-7. Polyester production.

Emissions And Controls - Air pollutant emissions from polyester fiber production include polymer dust from drying operations, volatilized residual monomer, fiber lubricants (in the form of fume or oil smoke), and the burned polymer and combustion products from cleaning the spinning equipment. Relative to the solvent spinning processes, the melt spinning of polyester fibers does not generate significant amounts of volatilized monomer or polymer, so emission control measures typically are not used in the spinning area. Finish oils that are applied in polyester fiber spinning operations are usually recovered and recirculated. When applied, finish oils are vaporized in the spin cell to some extent and, in some instances, are vented to either demisters, which remove some of the oils, or catalytic incinerators, which oxidize significant quantities of volatile hydrocarbons. Small amounts of finish oils are vaporized in the post-spinning process. Vapors from hot draw operations are typically controlled by such devices as electrostatic precipitators. Emissions from most other steps are not controlled.

Acrylic And Modacrylic Fiber Process Description^{5,18-24,53} - Acrylic and modacrylic fibers are based on acrylonitrile monomer, which is derived from propylene and ammonia. Acrylics are defined as those fibers that are composed of at least 85 percent acrylonitrile. Modacrylics are defined as those fibers that are composed of between 35 and 85 percent acrylonitrile. The remaining composition of the fiber typically includes at least one of the following - methyl methacrylate, methyl acrylate, vinyl acetate, vinyl chloride, or vinylidene chloride. Polyacrylonitrile fiber polymers are produced by the

industry using two methods, suspension polymerization and solution polymerization. Either batch or continuous reaction modes may be employed.

As shown in Figures 5.19-8 and 5.19-9, the polymer is dissolved in a suitable solvent, such as dimethylformamide or dimethylacetamide. Additives and delusterants are added, and the solution is usually filtered in plate and frame presses. The solution is then pumped through a manifold to the spinnerets (usually a bank of 30 to 50 per machine). At this point in the process, either wet or dry spinning may be used to form the acrylic fibers. The spinnerets are in a spinning bath for wet spun fiber, or at the top of an enclosed column for dry spinning. The wet spun filaments are pulled from the bath on takeup wheels, then washed to remove more solvent. After washing, the filaments are gathered into a tow band, stretched to improve strength, dried, crimped, heat set, and then cut into staple. The dry spun filaments are gathered into a tow band, stretched, dried, crimped, and cut into staple.

Emissions And Controls - Air pollutant emissions from the production of acrylic and modacrylic fibers include emissions of acrylonitrile (volatilized residual monomer), solvents, additives, and other organics used in fiber processing. As shown in Figures 5.19-8 and 5.19-9, both the wet and the dry spinning processes have many emission points. The major emission areas for the wet spin fiber process are the spinning and washing steps. The major emission areas from dry spinning of acrylic and modacrylic fibers are the spinning and post-spinning areas, up through and including drying. Solvent recovery in dry-spinning of modacrylic fibers is also a major emission point.

The most cost-effective method for reducing solvent VOC emissions from both wet and dry spinning processes is a solvent recovery system. In wet spinning processes, distillation is used to recover and recycle solvent from the solvent/water stream that circulates through the spinning, washing, and drawing operations. In dry spinning processes, control techniques include scrubbers, condensers, and carbon adsorption. Scrubbers and condensers are used to recover solvent emissions from the spinning cells and the dryers. Carbon adsorption is used to recover solvent emissions from storage tank vents and from mixing and filtering operations. Distillation columns are also used in dry spinning processes to recover solvent from the condenser, scrubber, and wash water (from the washing operation).

Nylon Fiber 6 and 66 Process Description^{5,17,24-27} - Nylon 6 polymer is produced from caprolactam. Caprolactam is derived most commonly from cyclohexanone, which in turn comes from either phenol or cyclohexane. About 70 percent of all nylon 6 polymer is produced by continuous polymerization. Nylon 66 polymer is made from adipic acid and hexamethylene diamine, which react to form hexamethylene diammonium adipate (AH salt). The salt is then washed in a methyl alcohol bath. Polymerization then takes place under heat and pressure in a batch process. The fiber spinning and processing procedures are the same as described earlier in the description of melt spinning.

Emissions And Controls - The major air pollutant emissions from production of nylon 6 fibers are volatilized monomer (caprolactam) and oil vapors or mists. Caprolactam emissions may occur at the spinning step, because the polymerization reaction is reversible and exothermic, and the heat of extrusion causes the polymer to revert partially to the monomer form. A monomer recovery system is used on caprolactam volatilized at the spinneret

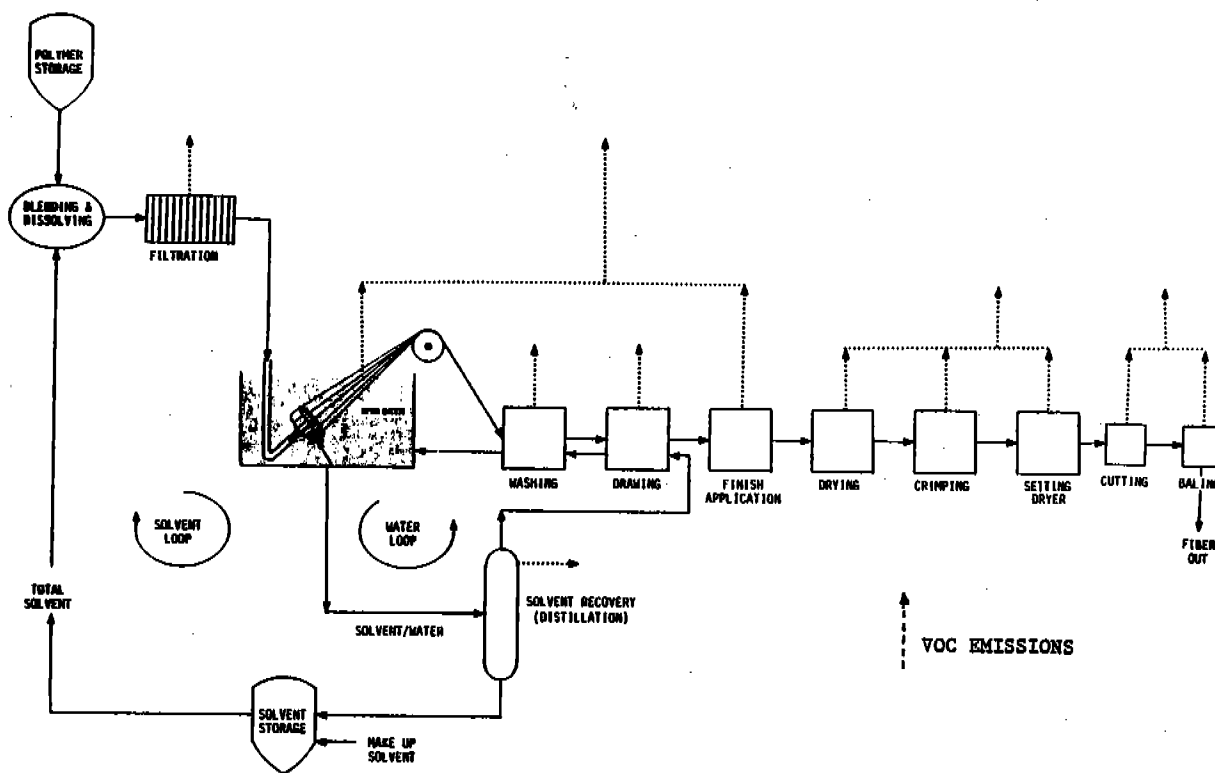


Figure 5.19-8. Acrylic fiber wet spinning.

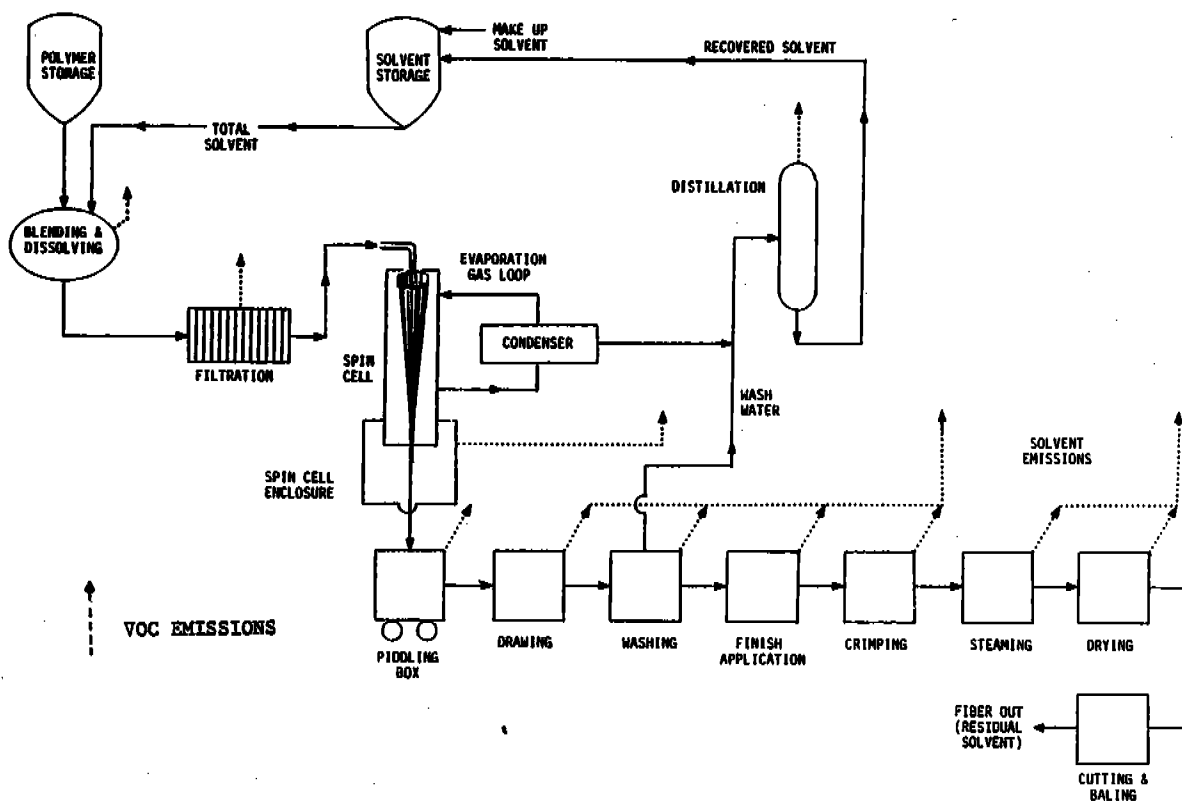


Figure 5.19-9. Acrylic fiber dry spinning.

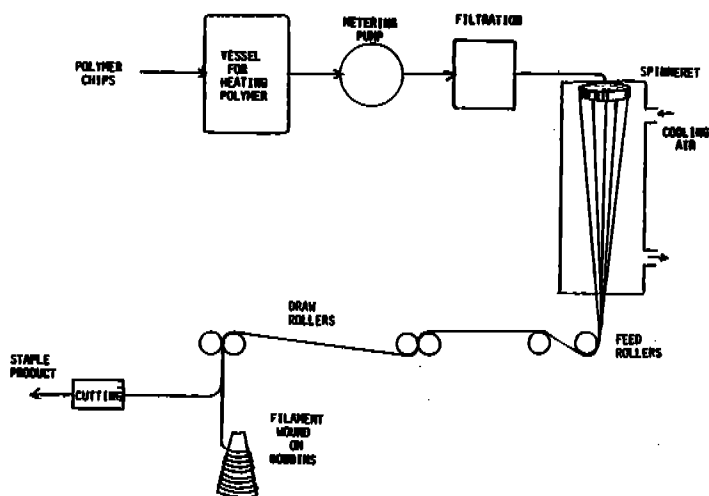


Figure 5.19-10. Nylon production.

during nylon 6 fiber formation. Monomer recovery systems are not used in nylon 66 (polyhexamethylene adipamide) spinning operations, since nylon 66 does not contain a significant amount of residual monomer. Emissions, though small, are in some instances controlled by catalytic incinerators. The finish oils, plasticizers and lubricants applied to both nylon 6 and 66 fibers during the spinning process are vaporized during post-spinning processes and, in some instances, such as the hot drawing of nylon 6, are vented to fabric filters, scrubbers and/or electrostatic precipitators.

Polyolefin Fiber Process Description^{2,5,28-30} - Polyolefin fibers are molecularly oriented extrusions of highly crystalline olefinic polymers, predominantly polypropylene. Melt spinning of polypropylene is the method of choice because the high degree of polymerization makes wet spinning or dissolving of the polymer difficult. The fiber spinning and processing procedures are generally the same as described earlier for melt spinning. Polypropylene is also manufactured by the split film process, in which it is extruded as a film and then stretched and split into flat filaments, or narrow tapes, that are twisted or wound into a fiber. Some fibers are manufactured as a combination of nylon and polyolefin polymers, being melted together in a ratio of about 20 percent nylon 6 and 80 percent polyolefin such as polypropylene, and being spun from this melt. Polypropylene is processed more like nylon 6 than nylon 66, because of the lower melting point 203°C (397°F) for nylon 6 versus 263°C (505°F) for nylon 66.

Emissions And Controls - Limited information is available on emissions from the actual spinning or processing of polyolefin fibers. The available data quantify and describe the emissions from the extruder/pelletizer stage, the last stage of polymer manufacture, and from just before the melting of the polymer for spinning. VOC content of the dried polymer after extruding and

pelletizing was found to be as much as 0.5 weight percent. Assuming the content is as high as 0.5 percent and that all this VOC is lost in the extrusion and processing of the fiber (melting, spinning, drawing, winding, etc.), there would be 5 pounds of VOC emissions per 1,000 pounds of polyolefin fiber. The VOCs in the dried polymer are hexane, propane and methanol, and the approximate proportions are 1.6 pounds of hexane, 1.6 pounds of propane and 1.8 pounds of methanol.

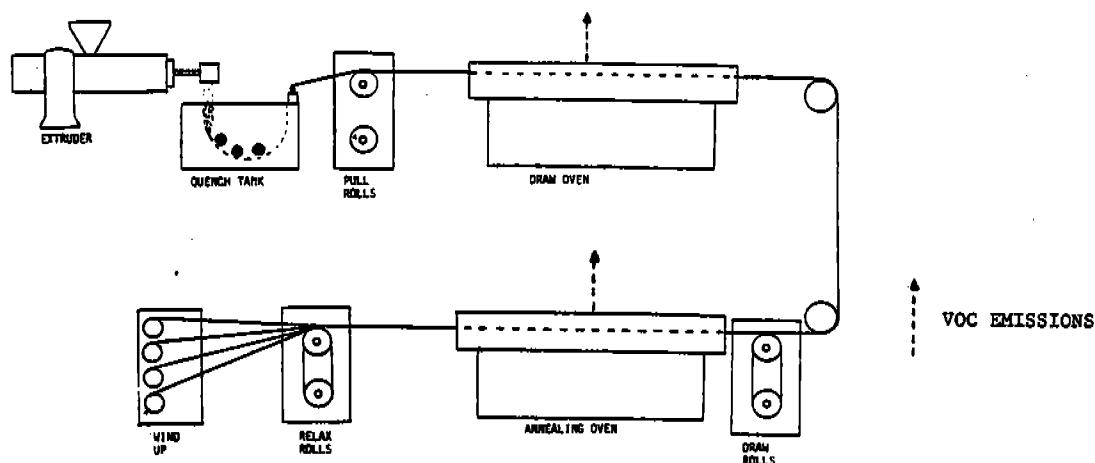


Figure 5.19-11. Polyolefin fiber production

During processing, lubricant and finish oils are added to the fiber, and some of these additives are driven off in the form of aerosols during processing. No specific information has been obtained to describe the oil aerosol emissions for polyolefin processing, but certain assumptions may be made to provide reasonably accurate values. Because polyolefins are melt spun similarly to other melt spun fibers (nylon 6, nylon 66, polyester, etc.), a fiber similar to the polyolefins would exhibit similar emissions. Processing temperatures are similar for polyolefins and nylon 6. Thus, aerosol emission values for nylon 6 can be assumed valid for polyolefins.

Spandex Fiber Manufacturing Process Description^{5,31-33} - Spandex is a generic name for a polyurethane fiber in which the fiber-forming substance is a long chain of synthetic polymer comprising of at least 85 percent of a segmented polyurethane. In between the urethane groups, there are long chains which may be polyglycols, polyesters or polyamides. Being spun from a polyurethane (a rubber-like material), spandex fibers are elastomeric, that is, they stretch. Spandex fibers are used in such stretch fabrics as belts, foundation garments, surgical stockings, and stocking tops.

Spandex is produced by two different processes in the United States. One process is similar in some respects to that used for acetate textile yarn, in that the fiber is dry spun, immediately wound onto takeup bobbins, and then twisted or processed in other ways. This process is referred to as dry spinning. The other process, which uses reaction spinning, is substantially different from any other fiber forming process used by domestic synthetic fiber producers.

Spandex Dry Spun Process Description - This manufacturing process, which is illustrated in Figure 5.19-12, is characterized by use of solution polymerization and dry spinning with an organic solvent. Tetrahydrofuran is the principal raw material. The compound's molecular ring structure is opened, and the resulting straight chain compound is polymerized to give a low molecular weight polymer. This polymer is then treated with an excess of a di-isocyanate. The reactant, with any unreacted di-isocyanate, is next reacted with some diamine, with monoamine added as a stabilizer. This final polymerization stage is carried out in dimethylformamide solution, and then the spandex is dry spun from this solution. Immediately after spinning, spandex yarn is wound onto a bobbin as continuous filament yarn. This yarn is later transferred to large spools for shipment or for further processing in another part of the plant.

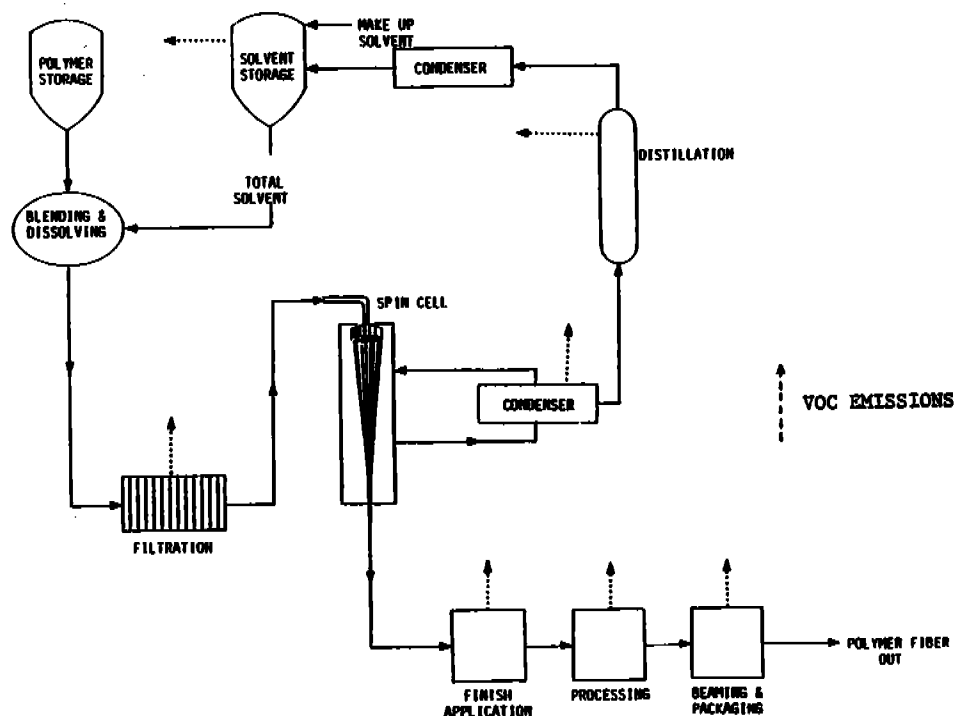


Figure 5.19-12. Spandex dry spinning.

Emissions And Controls - The major emissions from the spandex dry spinning process are volatilized solvent losses, which occur at a number of points of production. Solvent emissions occur during filtering of the spin dope, spinning of the fiber, treatment of the fiber after spinning, and the solvent recovery process. The emission points from this process are also shown in Figure 5.19-12.

Total emissions from spandex fiber dry spinning are considerably lower than from other dry spinning processes. It appears that the single most influencing factor that accounts for the lower emissions is that, because of nature of the polymeric material and/or spinning conditions, the amount of residual solvent in the fiber as it leaves the spin cell is considerably lower than other dry spun fibers. This situation may be because of the lower

solvent/polymer ratio that is used in spandex dry spinning. Less solvent is used for each unit of fiber produced, relative to other fibers. A condensation system is used to recover solvent emissions from the spin cell exhaust gas. Recovery of solvent emissions from this process is as high as 99 percent. Since the residual solvent in the fiber leaving the spin cell is much lower than for other fiber types, the potential for economic capture and recovery is also much lower. Therefore, these post-spinning emissions, which are small, are not controlled.

Spandex Reaction Spun Process Description - In the reaction spun process, a polyol (typically, polyester) is reacted with an excess of di-isocyanate to form the urethane prepolymer, which is pumped through spinnerets at a constant rate into a bath of dilute solution of ethylenediamine in toluene. The ethylenediamine reacts with isocyanate end groups on the resin to form long chain cross-linked polyurethane elastomeric fiber. The final cross linking reaction takes place after the fiber has been spun. The fiber is transported from the bath to an oven, where solvent is evaporated. After drying, the fiber is lubricated and is wound on tubes for shipment.

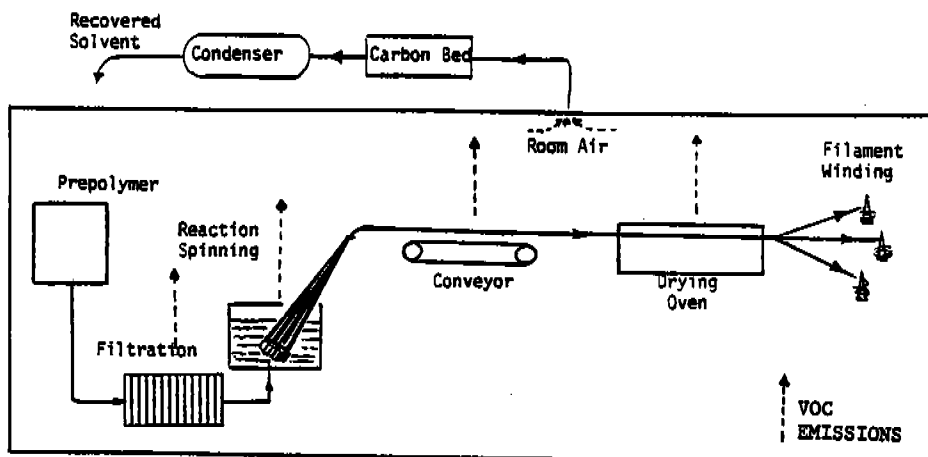


Figure 5.19-13. Spandex reaction spinning.

Emissions And Controls - Essentially all air that enters the spinning room is drawn into the hooding that surrounds the process equipment and then leads to a carbon adsorption system. The oven is also vented to the carbon adsorber. The gas streams from the spinning room and oven are combined and cooled in a heat exchanger before they enter the activated carbon bed.

Vinyon Fiber Process Description^{5,34} - Vinyon is a copolymer of vinyl chloride (88 percent) and vinyl acetate (12 percent). The polymer is dissolved in a ketone (acetone or methyl ethyl ketone) to make a 23 weight percent spinning solution. After filtering, the solution is extruded as filaments into warm air to evaporate the solvent and to allow its recovery and reuse. The spinning process is similar to that of cellulose acetate. After

spinning, the filaments are stretched to achieve molecular orientation to impart strength.

Emissions And Controls - Emissions occur at steps similar to those of cellulose acetate, at dope preparation and spinning, and as fugitive emissions, from the spun fiber during processes such as winding and stretching. The major source of VOC is the spinning step, where the warm air stream evaporates the solvent. This air/solvent stream is sent to either a scrubber or carbon adsorber for solvent recovery. Emissions may also occur at the exhausts from these control device.

Other Fibers - There are synthetic fibers manufactured on a small volume scale relative to the commodity fibers. Because of the wide variety of these fiber manufacturing processes, specific products and processes are not discussed. Table 5.19-3 lists some of these fibers and the respective producers.

TABLE 5.19-3. OTHER SYNTHETIC FIBERS AND THEIR MAKERS

Nomex (aramid)	DuPont
Kevlar (aramid)	DuPont
PBI (polybenzimidazole)	Celanese
Kynol (novoloid)	Carborundum
Teflon	DuPont

GLOSSARY

Crimping:	A process in which waves and angles are set into fibers, such as acrylic fiber filaments, to help simulate properties of natural fibers.
Coagulant:	A substance, either a salt or an acid, used to precipitate polymer solids out of emulsions or latexes.
Continuous filament yarn:	Very long fibers that have been converged to form a multifiber yarn, typically consisting of 15 to 100 filaments.
Cutting:	Refers to the conversion of tow to staple fiber.
Delusterant:	Fiber finishing additives (typically clays or barium sulfate) used to dull the surfaces of the fibers.

Dope: The polymer, either in molten form or dissolved in solvent, that is spun into fiber.

Drawing: The stretching of the filaments in order to increase the fiber's strength; also makes the fiber more supple and unshrinkable (that is, the stretch is irreversible). The degree of stretching varies with the yarn being spun.

Filament: The solidified polymer that has emerged from a single hole or orifice in a spinneret.

Filament yarn: (See continuous filament yarn)

Heat setting: The dimensional stabilization of the fibers with heat so that the fibers are completely undisturbed by subsequent treatments such as washing or dry cleaning at a lower temperature. To illustrate, heat setting allows a pleat to be retained in the fabric, while helping prevent undesirable creases later in the life of the fabric.

Lubrication: The application of oils or similar substances to the fibers in order, for example, to facilitate subsequent handling of the fibers and to provide static suppression.

Spinneret: A spinneret is used in the production of all man-made fiber whereby liquid is forced through holes. Filaments emerging from the holes are hardened and solidified. The process of extrusion and hardening is called spinning.

Spun yarn: Yarn made from staple fibers that have been twisted or spun together into a continuous strand.

Staple: Lengths of fiber made by cutting man-made fiber tow into short (1- to 6-inch) and usually uniform lengths, which are subsequently twisted into spun yarn.

Tow: A collection of many (often thousands) parallel, continuous filaments, without twist, which are grouped together in a rope-like form having a diameter of about one-quarter inch.

Twisting: Giving the filaments in a yarn a very slight twist that prevents the fibers from sliding over each other when pulled, thus increasing the strength of the yarn.

References for Section 5.19

1. Man-made Fiber Producer's Base Book, Textile Economics Bureau Incorporated, New York, NY, 1977.
2. "Fibers - 540.000", Chemical Economics Handbook, Menlo Park, CA, March 1978.

3. Industrial Process Profiles For Environmental Use - Chapter 11 - The Synthetic Fiber Industry, EPA Contract No. 68-02-1310, Aeronautical Research Associates of Princeton, Princeton, NJ, November 1976.
4. R. N. Shreve, Chemical Process Industries, McGraw-Hill Book Company, New York, NY, 1967.
5. R. W. Moncrief, Man-made Fibers, Newnes-Butterworth, London, 1975.
6. Guide To Man-made Fibers, Man-made Fiber Producers Association, Inc. Washington, DC, 1977.
7. "Trip Report/Plant Visit To American Enka Company, Lowland, Tennessee", Pacific Environmental Services, Inc., Durham, NC, January 22, 1980.
8. "Report Of The Initial Plant Visit To Avtex Fibers, Inc., Rayon Fiber Division, Front Royal, VA", Pacific Environmental Services, Inc., Durham, NC, January 15, 1980.
9. "Fluidized Recovery System Nabs Carbon Disulfide", Chemical Engineering, 70(8):92-94, April 15, 1963.
10. Standards Of Performance For Synthetic Fibers NSPS, Docket No. A-80-7, II-B-3, "Viscose Rayon Fiber Production - Phase I Investigation", U. S. Environmental Protection Agency, Washington, DC, February 25, 1980.
11. "Report Of The Initial Plant Visit To Tennessee Eastman Company Synthetic Fibers Manufacturing", Kingsport, TN, Pacific Environmental Services, Inc., Durham, NC, December 13, 1979.
12. "Report Of The Phase II Plant Visit To Celanese's Celriver Acetate Plant In Rock Hill, SC", Pacific Environmental Services, Inc., Durham, NC, May 28, 1980.
13. "Report Of The Phase II Plant Visit To Celanese's Celco Acetate Fiber Plant In Narrows, VA", Pacific Environmental Services, Inc., Durham, NC, August 11, 1980.
14. Standards Of Performance For Synthetic Fibers NSPS, Docket No. A-80-7, II-I-43, U. S. Environmental Protection Agency, Washington, DC, December 1979.
15. E. Welfers, "Process And Machine Technology Of Man-made Fibre Production", International Textile Bulletin, World Spinning Edition, Schlieren/Zurich, Switzerland, February 1978.
16. Written communication from R. B. Hayden, E. I. duPont de Nemours and Co., Wilmington, DE, to E. L. Bechstein, Pullman, Inc., Houston, TX, November 8, 1978.
17. Written communication from E. L. Bechstein, Pullman, Inc., Houston, TX, to R. M. Clowers, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 17, 1978 .

18. "Report Of The Plant Visit To Badische Corporation's Synthetic Fibers Plant In Williamsburg, VA", Pacific Environmental Services, Inc., Durham, NC, November 28, 1979.
19. "Report Of The Initial Plant Visit To Monsanto Company's Plant In Decatur, AL", Pacific Environmental Services, Inc., Durham, NC, April 1, 1980.
20. "Report Of The Initial Plant Visit To American Cyanamid Company", Pacific Environmental Services, Inc., Durham, NC, April 11, 1980.
21. Written communication from G. T. Esry, E. I. duPont de Nemours and Co., Wilmington, DE, to D. R. Goodwin, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 7, 1978.
22. "Report Of The Initial Visit To duPont's Acrylic Fiber Plant In Waynesboro, VA", Pacific Environmental Services, Inc., Durham, NC, May 1, 1980.
23. "Report Of The Phase II Plant Visit To duPont's Acrylic Fiber May Plant In Camden, SC", Pacific Environmental Services, Inc., Durham, NC, August 8, 1980.
24. C. N. Click and D. K. Webber, Polymer Industry Ranking By VOC Emission Reduction That Would Occur From New Source Performance Standards, EPA Contract No. 68-02-2619, Pullman, Inc., Houston, TX, August 30, 1979.
25. Written communication from E. L. Bechstein, Pullman, Inc., Houston, TX, to R. M. Clowers, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 28, 1978.
26. Written communication from R. B. Hayden, E. I. duPont de Nemours and Co., Wilmington, DE, to W. Talbert, Pullman, Inc., Houston, TX, October 17, 1978.
27. "Report Of The Initial Plant Visit To Allied Chemical's Synthetic Fibers Division, Chesterfield, VA, Pacific Environmental Services, Inc., Durham, NC, November 27, 1979.
28. Background Information Document -- Polymers And Resins Industry, EPA-450/3-83-019a, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1984.
29. H. P. Frank, Polypropylene, Gordon and Breach Science Publishers, New York, NY, 1968.
30. A. V. Galanti and C. L. Mantell, Polypropylene - Fibers and Films, Plenum Press, New York, NY, 1965.
31. D. W. Crumpler, "Trip Report - Plant Visit To Globe Manufacturing Company", D. Crumpler, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 16 and 17, 1981.

32. "Standards Of Performance For Synthetic Fibers NSPS, Docket No. A-80-7, II-I-115, Lycra Reamout Plan," U. S. Environmental Protection Agency, Washington, DC, May 10, 1979.
33. "Standards Of Performance For Synthetic Fibers NSPS, Docket No. A-80-7, II-I-95," U. S. Environmental Protection Agency, Washington, DC, March 2, 1982.
34. Written communication from W. K. Mohny, Avtex Fibers, Inc., Meadville, PA, to R. Manley, Pacific Environmental Services, Durham, NC, April 14, 1981.
35. Personal communication from J. H. Cosgrove, Avtex Fibers, Inc., Front Royal, VA, to R. Manley, Pacific Environmental Services, Inc., Durham, NC, November 29, 1982.
36. Written communication from T. C. Benning, Jr., American Enka Co., Lowland, TN, to R. A. Zerbonia, Pacific Environmental Services, Inc., Durham, NC, February 12, 1980.
37. Written communication from R. O. Goetz, Virginia State Air Pollution Control Board, Richmond, VA, to Director, Region II, Virginia State Air Pollution Control Board, Richmond, VA, November 22, 1974.
38. Written communication from H. S. Hall, Avtex Fibers, Inc., Valley Forge, PA, to J. R. Farmer, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 12, 1980.
39. Written communication from J. C. Pullen, Celanese Fibers Co., Charlotte, NC, to R. A. Zerbonia, Pacific Environmental Services, Inc., Durham, NC, July 3, 1980.
40. Written communication from J. C. Pullen, Celanese Fibers Co., Charlotte, NC, to National Air Pollution Control Techniques Advisory Committee, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 8, 1981.
41. "Report Of The Initial Plant Visit To Tennessee Eastman Company Synthetic Fibers Manufacturing, Kingsport, TN", Pacific Environmental Services, Inc., Durham, NC, December 13, 1979.
42. Written communication from J. C. Edwards, Tennessee Eastman Co., Kingsport, TN, to R. Zerbonia, Pacific Environmental Services, Inc., Durham, NC, April 28, 1980.
43. Written communication from C. R. Earnhart, E.I. duPont de Nemours and Co., Camden, SC, to D. W. Crumpler, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 5, 1981.
44. C. N. Click and D. K. Weber, Emission Process And Control Technology Study Of The ABS/SAN, Acrylic Fiber, And NBR Industries, EPA Contract No. 68-02-2619, Pullman, Inc., Houston, TX, April 20, 1979.

45. Written communication from D. O. Moore, Jr., Pullman, Inc., Houston, TX, to D. C. Mascone, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 18, 1979.
46. Written communication from W. M. Talbert, Pullman, Inc., Houston, TX, to R. J. Kucera, Monsanto Textiles Co., Decatur, AL, July 17, 1978.
47. Written communication from M. O. Johnson, Badische Corporation, Williamsburg, VA, to D. R. Patrick, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1, 1979.
48. Written communication from J. S. Lick, Badische Corporation, Williamsburg, VA, to D. R. Goodwin, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 14, 1980.
49. P. T. Wallace, "Nylon Fibers", Chemical Economics Handbook, Stanford Research Institute, Menlo Park, CA, December 1977.
50. Written communication from R. Legendre, Globe Manufacturing Co., Fall River, MA, to Central Docket Section, U. S. Environmental Protection Agency, Washington, DC, August 26, 1981.
51. Written communication from R. Legendre, Globe Manufacturing Co., Fall River, MA, to J. Farmer, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 26, 1980.
52. Written communication from R. H. Hughes, Avtex Fibers Co., Valley Forge, PA, to R. Manley, Pacific Environmental Services, Inc., Durham, NC, February 28, 1983.
53. "Report Of The Phase II Plant Visit, duPont's Acrylic Fiber May Plant In Camden, SC", Pacific Environmental Services, Inc., Durham, NC, April 29, 1980.

Particulate emissions from sinter machines range from 5 to 20 percent of the concentrated ore feed. In product weight, typical emissions are estimated at 106.5 kilograms per megagram (213 pounds per ton) of lead produced. This value and other particulate and SO₂ factors appear in Table 7.6-1.

Typical material balances from domestic lead smelters indicate that about 15 percent of the sulfur in ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only half of this amount, about 7 percent of the total sulfur in the ore is emitted as SO₂.

The remainder is captured by the slag. The concentration of this SO₂ stream can vary from 1.4 to 7.2 grams per cubic meter (500 to 2500 parts per million) by volume, depending on the amount of dilution air injected to oxidize the carbon monoxide and to cool the stream before baghouse particulate removal.

Particulate emissions from blast furnaces contain many kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic and other metallic compounds associated with lead ores. These particles readily agglomerate and are primarily submicron in size, difficult to wet, and cohesive. They will bridge and arch in hoppers. On average, this dust loading is quite substantial, as is shown in Table 7.6-1.

Minor quantities of particulate are generated by ore crushing and materials handling operations, and these emission factors are also presented in Table 7.6-1.

TABLE 7.6-1. UNCONTROLLED EMISSION FACTORS FOR PRIMARY LEAD SMELTING^a

EMISSION FACTOR RATING: B						
Process	Total Particulate		Sulfur dioxide		Lead	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Ore crushing ^b	1.0	2.0	-	-	0.15	0.3
Sintering (updraft) ^c	106.5	213.0	275.0	550.0	87 (4.2-170)	174 (8.4-340)
Blast furnace ^d	180.5	361.0	22.5	45.0	29 (8.7-50)	59 (17.5-100)
Dross reverberatory furnace	10.0	20.0	Neg	Neg	2.4 (1.3-3.5)	4.8 (2.6-7.0)
Materials handling ^f	2.5	5.0	-	-	-	-

^aOre crushing factors expressed as kg/Mg (lb/ton) of crushed ore. All other factors are kg/Mg (lb/ton) of lead product. Dash = no data. Neg = negligible.

^bReferences 2,13.

^cReferences 1, 4-6, 11, 14-17, 21-22.

^dReferences 1-2, 7, 12, 14, 16-17, 19.

^eReferences 2, 11-12, 14, 18, 20.

^fReference 2.

Table 7.6-2 and Figure 7.6-2 present size specific emission factors for the controlled emissions from a primary lead blast furnace. No other size distribution data can be located for point sources within a primary lead processing plant. Lacking definitive data, size distributions for uncontrolled assuming that the uncontrolled size distributions for the sinter machine and blast furnace are the same as for fugitive emissions from these sources.

Tables 7.6-3 through 7.6-7 and Figures 7.6-3 through 7.6-7 present size specific emission factors for the fugitive emissions generated at a primary lead processing plant. The size distribution of fugitive emissions at a primary lead processing plant is fairly uniform, with approximately 79 percent of these emissions at less than 2.5 micrometers. Fugitive emissions less than 0.625 micrometers in size make up approximately half of all fugitive emissions, except from the sinter machine, where they constitute about 73 percent.

Emission factors for total fugitive particulate from primary lead smelting processes are presented in Table 7.6-8. The factors are based on a combination of engineering estimates, test data from plants currently operating, and test data from plants no longer operating. The values should be used with caution, because of the reported difficulty in accurately measuring the source emission rates.

Emission controls on lead smelter operations are for particulate and sulfur dioxide. The most commonly employed high efficiency particulate control devices are fabric filters and electrostatic precipitators (ESP), which often follow centrifugal collectors and tubular coolers (pseudogravity collectors).

Three of the six lead smelters presently operating in the United States use single absorption sulfuric acid plants to control SO₂ emissions from sinter machines and, occasionally, from blast furnaces. Single stage plants can attain sulfur oxide levels of 5.7 grams per cubic meter (2000 parts per million), and dual stage plants can attain levels of 1.6 grams per cubic meter (550 parts per million). Typical efficiencies of dual stage sulfuric acid plants in removing sulfur oxides can exceed 99 percent. Other technically feasible SO₂ control methods are elemental sulfur recovery plants and dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are given in Table 7.6-9.

References For Section 7.10

1. Summary Of Factors Affecting Compliance By Ferrous Foundries. Volume I: Text, EPA-340/1-80-020, U. S. Environmental Protection Agency, Washington, DC, January 1981.
2. Air Pollution Aspects Of The Iron Foundry Industry, APTD-0806, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.
3. Systems Analysis Of Emissions And Emission Control In The Iron Foundry Industry. Volume II: Exhibits, APTD-0645, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.
4. J. A. Davis, et al., Screening Study On Cupolas And Electric Furnaces In Gray Iron Foundries, EPA Contract No. 68-01-0611, Battelle Laboratories, Columbus, OH, August 1975.
5. R. W. Hein, et al., Principles Of Metal Casting, McGraw-Hill, New York, 1967.
6. P. Fennelly and P. Spawn, Air Pollution Control Techniques For Electric Arc Furnaces In The Iron And Steel Foundry Industry, EPA-450/2-78-024, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.
7. R. D. Chmielewski and S. Calvert, Flux Force/Condensation Scrubbing For Collecting Fine Particulate From Iron Melting Cupola, EPA-600/7-81-148, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.
8. W. F. Hammond and S. M. Weiss, "Air Contaminant Emissions From Metallurgical Operations In Los Angeles County", Presented at the Air Pollution Control Institute, Los Angeles, CA, July 1964.
9. Particulate Emission Test Report On A Gray Iron Cupola At Cherryville Foundry Works, Cherryville, NC, State Department Of Environmental Health And Natural Resources, Raleigh, NC, December 18, 1975.
10. J. W. Davis and A. B. Draper, Statistical Analysis Of The Operating Parameters Which Affect Cupola Emissions, DOE Contract No. EY-76-5-02-2840.*000, Center For Air Environment Studies, Pennsylvania State University, University Park, PA, December 1977.
11. Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.
12. Written communication from Dean Packard, Department Of Natural Resources, Madison, WI, to Douglas Seeley, Alliance Technology, Bedford, MA, April 15, 1982.

13. Particulate Emissions Testing At Opelika Foundry, Birmingham, AL, Air Pollution Control Commission, Montgomery, AL, November 1977 - January 1978.
14. Written communication from Minnesota Pollution Control Agency, St. Paul, MN, to Mike Jasinski, Alliance Technology, Bedford, MA, July 12, 1982.
15. Stack Test Report, Dunkirk Radiator Corporation Cupola Scrubber, State Department Of Environmental Conservation, Region IX, Albany, NY, November 1975.
16. Particulate Emission Test Report For A Scrubber Stack For A Gray Iron Cupola At Dewey Brothers, Goldsboro, NC, State Department Of Environmental Health And Natural Resources, Raleigh, NC, April 7, 1978.
17. Stack Test Report, Worthington Corp. Cupola, State Department Of Environmental Conservation, Region IX, Albany, NY, November 4-5, 1976.
18. Stack Test Report, Dresser Clark Cupola Wet Scrubber, Orlean, NY, State Department Of Environmental Conservation, Albany, NY, July 14 & 18, 1977.
19. Stack Test Report, Chevrolet Tonawanda Metal Casting, Plant Cupola #3 And Cupola #4, Tonawanda, NY, State Department Of Environmental Conservation, Albany, NY, August 1977.
20. Stack Analysis For Particulate Emission, Atlantic States Cast Iron Foundry/Scrubber, State Department Of Environmental Protection, Trenton, NJ, September 1980.
21. S. Calvert, et al., Fine Particle Scrubber Performance, EPA-650/2-74-093, U. S. Environmental Protection Agency, Cincinnati, OH, October 1974.
22. S. Calvert, et al., National Dust Collector Model 850 Variable Rod Module Venturi Scrubber Evaluation, EPA-600/2-76-282, U. S. Environmental Protection Agency, Cincinnati, OH, December 1976.
23. Source Test, Electric Arc Furnace At Paxton-Mitchell Foundry, Omaha, NB, Midwest Research Institute, Kansas City, MO, October 1974.
24. Source Test, John Deere Tractor Works, East Moline, IL, Gray Iron Electric Arc Furnace, Walden Research, Wilmington, MA, July 1974.
25. S. Gronberg, Characterization Of Inhalable Particulate Matter Emissions From An Iron Foundry, Lynchburg Foundry, Archer Creek Plant, EPA-600/X-85-328, U. S. Environmental Protection Agency, Cincinnati, OH, August 1984.
26. Particulate Emissions Measurements From The Rotocclone And General Casting Shakeout Operations Of United States Pipe & Foundry, Inc., Anniston, AL, Black, Crow and Eidsness, Montgomery, AL, November 1973,

27. Report Of Source Emissions Testing At Newbury Manufacturing. Talladega, AL, State Air Pollution Control Commission, Montgomery, AL, May 15-16, 1979.
28. Particulate Emission Test Report For A Gray Iron Cupola At Hardy And Newson, La Grange, NC, State Department Of Environmental Health And Natural Resources, Raleigh, NC, August 2-3, 1977.
29. H. R. Crabaugh, et al., "Dust And Fumes From Gray Iron Cupolas: How Are They Controlled In Los Angeles County?", Air Repair, 4(3):125-130, November 1954.
30. J. M. Kane, "Equipment For Cupola Control", American Foundryman's Society Transactions, 64:525-531, 1956.
31. Control Techniques For Lead Air Emissions, 2 Volumes, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.
32. W. E. Davis, Emissions Study Of Industrial Sources Of Lead Air Pollutants, 1970, APTD-1543, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1973.
33. Emission Test No. EMB-71-CI-27, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1972.
34. Emission Test No. EMB-71-CI-30, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.
35. John Zoller, et al., Assessment Of Fugitive Particulate Emission Factors For Industrial Processes, EPA-450/3-78-107, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.
36. John Jeffery, et al., Gray Iron Foundry Industry Particulate Emissions: Source Category Report, EPA-600/7-86-054, U. S. Environmental Protection Agency, Cincinnati, OH, December 1986.

TABLE 10.1-1. EMISSION FACTORS FOR KRAFT PULPING^a

EMISSION FACTOR RATING: A

Source	Type of control	Particulate		Sulfur dioxide (SO ₂)		Carbon monoxide (CO)		Hydrogen sulfide (S ^m)		RSH, RSR, RSSR (S ^m)	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Digester relief and blow tank Brown stock washer Multiple effect evaporator Recovery boiler and direct evaporator	Untreated ^b	-	-	-	-	-	-	0.02	0.03	0.6	1.2
	Untreated ^b	-	-	-	-	-	-	0.01	0.02	0.2 ^c	0.4 ^c
	Untreated ^b	-	-	-	-	-	-	0.55	1.1	0.05	0.1
	Untreated ^d	90	180	3.5	7	5.5	11	6 ^e	12 ^e	1.5 ^e	3 ^e
Noncontact recovery boiler without direct contact evaporator	Venturi scrubber ^f	24	48	3.5	7	5.5	11	6 ^e	12 ^e	1.5 ^e	3 ^e
	ESP	1	2	3.5	7	5.5	11	6 ^e	12 ^e	1.5 ^e	3 ^e
	Auxiliary scrubber	1.5-7.58	3-158	-	-	-	-	6 ^e	12 ^e	1.5 ^e	3 ^e
	Untreated ESP	115	230	-	-	5.5	11	0.05 ^h	0.1 ^h	-	-
Smelt dissolving tank	Untreated	1	2	-	-	5.5	11	0.05 ^h	0.1 ^h	-	-
	Mesh pad	3.5	7	0.1	0.2	-	-	0.1 ^j	0.2 ^j	0.15 ^j	0.3 ^j
	Scrubber	0.5	1	0.1	0.2	-	-	0.1 ^j	0.2 ^j	0.15 ^j	0.3 ^j
	Scrubber	0.1	0.2	-	-	-	-	0.1 ^j	0.2 ^j	0.15 ^j	0.3 ^j
Lime kiln	Untreated	28	56	0.15	0.3	0.05	0.1	0.25 ^m	0.5 ^m	0.1 ^m	0.2 ^m
	Scrubber or ESP	0.25	0.5	-	-	0.05	0.1	0.25 ^m	0.5 ^m	0.1 ^m	0.2 ^m
Turpentine condenser	Untreated	-	-	-	-	-	-	0.005	.01	0.25	0.5
Miscellaneous ⁿ	Untreated	-	-	-	-	-	-	-	-	0.25	0.5

References 8-10. Factors expressed in unit weight of air dried unbleached pulp (ADP). RSH = Methyl mercaptan. RSR = Dimethyl sulfide. RSSR = Dimethyl disulfide. ESP = Electrostatic precipitator. Dash = No data.

^bIf noncondensable gases from these sources are vented to lime kiln, recovery furnace or equivalent, the reduced sulfur compounds are destroyed.

^cApply with system using condensate as washing medium. When using fresh water, emissions are 0.05 (0.1).

^dApply when cyclonic scrubber or cascade evaporator is used for direct contact evaporation, with no further controls. Emissions reduced by 50% with black liquor oxidation and can be cut 95 - 99% when oxidation is complete and recovery furnace is operated optimally.

^eApply when venturi scrubber is used for direct contact evaporation, with no further controls.

^fUse 7.5 (15) when auxiliary scrubber follows venturi scrubber, and 1.5 (3) when it follows ESP.

^gApply when recovery furnace is operated optimally to control total reduced sulfur (TRS) compounds.

^hUsually reduced to 0.01 g/kg (0.02 lb/ton) ADP when water low in sulfides is used in smelt dissolving tank and associated scrubber.

ⁱUsually reduced to 0.015 g/kg (0.03 lb/ton) ADP with efficient mud washing, optimal kiln operation and added caustic in scrubbing water. With only efficient mud washing and optimal process control, TRS compounds reduced to 0.04 g/kg (0.08 lb/ton) ADP.

^jIncludes knotted vents, brownstock seal tanks, etc. When black liquor oxidation is included, emissions are 0.3 (0.6).

TABLE 10.1-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITH A DIRECT CONTACT EVAPORATOR AND AN ESP^a

EMISSION FACTOR RATING: C

Particle size (μm)	Cumulative mass % \leq stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	95.0	-	86	-
10	93.5	-	84	-
6	92.2	68.2	83	0.7
2.5	83.5	53.8	75	0.5
1.25	56.5	40.5	51	0.4
1.00	45.3	34.2	41	0.3
0.625	26.5	22.2	24	0.2
Total	100	100	90	1.0

^aReference 7. Dash = no data.

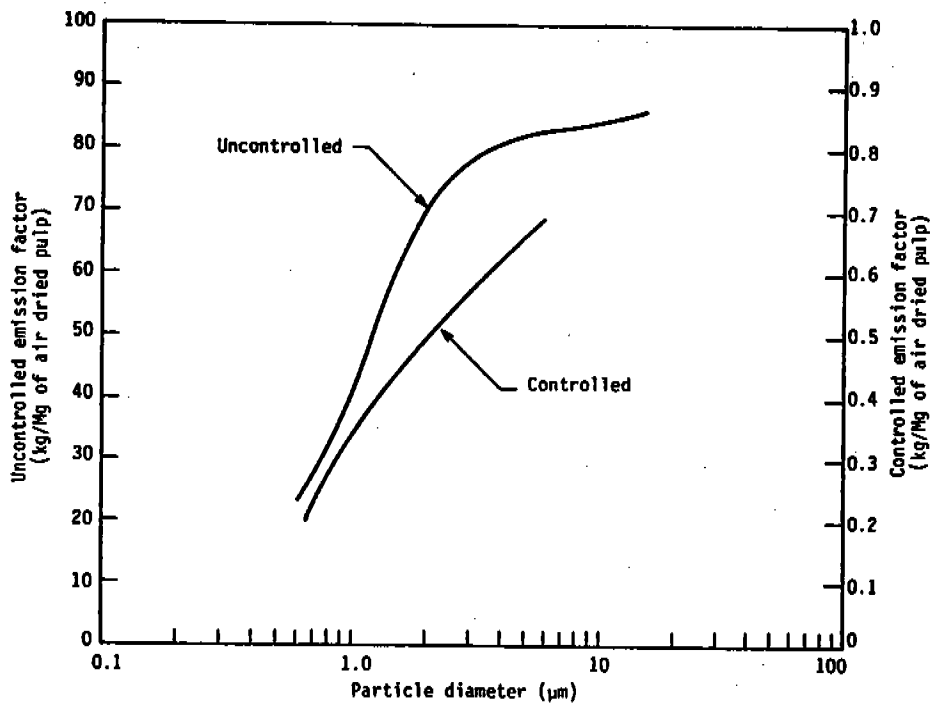


Figure 10.1-2. Cumulative particle size distribution and size specific emission factors for recovery boiler with direct contact evaporator and ESP.

In discussing prescribed burning, the combustion process is divided into preheating, flaming, glowing and smoldering phases. The different phases of combustion greatly affect the amount of emissions produced.⁵⁻⁷ The preheating phase seldom releases significant quantities of material to the atmosphere. Glowing combustion is usually associated with burning of large concentrations of woody fuels such as logging residue piles. The smoldering combustion phase is a very inefficient and incomplete combustion process that emits pollutants at a much higher ratio to the quantity of fuel consumed than does the flaming combustion of similar materials.

The amount of fuel consumed depends on the moisture content of the fuel.⁸⁻⁹ For most fuel types, consumption during the smoldering phase is much greatest when the fuel is driest. When lower layers of the fuel are moist, the fire usually is extinguished rapidly.¹⁰

The major pollutants from wildland burning are particulate, carbon monoxide and volatile organics. Nitrogen oxides are emitted at rates of from 1 to 4 grams per kilogram burned, depending on combustion temperatures. Emissions of sulfur oxides are negligible.¹¹⁻¹²

Particulate emissions depend on the mix of combustion phase, the rate of energy release, and the type of fuel consumed. All of these elements must be considered in selecting the appropriate emission factor for a given fire and fuel situation. In some cases, models developed by the U. S. Forest Service have been used to predict particulate emission factors and source strength.¹³ These models address fire behavior, fuel chemistry, and ignition technique, and they predict the mix of combustion products. There is insufficient knowledge at this time to describe the effect of fuel chemistry on emissions.

Table 11.1-3 presents emission factors from various pollutants, by fire and fuel configuration. Table 11.1-4 gives emission factors for prescribed burning, by geographical area within the United States. Estimates of the percent of total fuel consumed by region were compiled by polling experts from the Forest Service. The emission factors are averages and can vary by as much as 50 percent with fuel and fire conditions. To use these factors, multiply the mass of fuel consumed per hectare by the emission factor for the appropriate fuel type. The mass of fuel consumed by a fire is defined as the available fuel. Local forestry officials often compile information on fuel consumption for prescribed fires and have techniques for estimating fuel consumption under local conditions. The Southern Forestry Smoke Management Guidebook⁵ and the Prescribed Fire Smoke Management Guide¹⁵ should be consulted when using these emission factors.

The regional emission factors in Table 11.1-4 should be used only for general planning purposes. Regional averages are based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided. Table 11.1-4 should not be used to develop emission inventories and control strategies.

To develop state emission inventories, the user is strongly urged to contact that state's federal land management agencies and state forestry agencies that conduct prescribed burning to obtain the best information on such activities.

TABLE 11.1-3. EMISSION FACTORS FOR PRESCRIBED BURNING^a

Fire/fuel configuration	Phase	Pollutant (g/kg)						Fuel mix (%)	Emission Factor Rating
		Particulate		Carbon monoxide	Volatile organics				
		PM _{2.5}	PM ₁₀ Total		Methane	Nonmethane			
Broadcast logging slash Hardwood ^b	F	6	7	13	44	2.1	3.8	33	A
	S	13	14	20	146	8.0	7.7	67	A
	Fire	11	12	18	112	6.1	6.4		A
Conifer Short needle ^c	F	7	8	12	72	2.3	2.1	33	A
	S	14	15	19	226	7.2	4.2	67	A
	Fire	12	13	17	175	5.6	3.5		A
Long needle ^d	F	6	6	9	45	1.5	1.7	33	B
	S	16	17	25	166	7.7	5.4	67	B
	Fire	13	13	20	126	5.7	4.2		B
Logging slash debris Dozer piled conifer No mineral soil ^d	F	4	4	5	28	1.0	-	90	B
	S	6	7	14	116	8.7	-	10	B
	Fire	4	4	6	37	1.8	-		B
10-30% mineral soil ^e 25% organic soil ^e	S	-	-	25	200	-	-		D
	S	-	-	35	250	-	-		D
Range fire Juniper slash ^f	F	7	8	11	41	2.0	2.7		B
	S	12	13	18	125	10.3	7.8		B
	Fire	9	10	14	82	6.0	5.2		B
Sagebrush ^f	F	15	16	23	78	3.7	3.4		B
	S	13	15	23	106	6.2	7.3		B
	Fire	13	15	23	103	6.2	6.9		B

TABLE 11.1-3. EMISSION FACTORS FOR PRESCRIBED BURNING (cont.)^a

Fire/fuel configuration	Phase	Pollutant (g/kg)					Fuel mix (%)	Emission Factor Rating
		Particulate		Carbon monoxide	Volatile Organics			
		PM _{2.5}	PM ₁₀ Total		Methane	Nonmethane		
Line fire Conifer Long needle (pine)	Heading ^g	-	40	50	200	-	-	D
	Backing ^h	-	20	20	125	-	-	D
	Heading	-	15	17	150	-	-	D
	Back	-	15	15	100	-	-	D
	Fire	-	8	-	-	-	-	D
Palmetto/gallberry ^g			to					
			22					
Chaparral ^h Grasslands ^g	Heading	8	9	15	62	2.8	3.5	C
	Fire	-	10	10	75	-	-	D

^aReferences 7-8. Unless otherwise noted, determined by field testing of fires ≥ 1 acre size.

F = flaming. S = smoldering. Fire = weighted average of F and S. Dash = no data.

^bFor PM₁₀, Reference 7. Emission Factor Rating: C.^cFor PM₁₀, Reference 3,7. Emission Factor Rating: C.^dFor PM₁₀, Reference 3,7. Emission Factor Rating: D.^eReference 12. Determined using laboratory combustion hood.^fReference 16.^gReferences 13-14. Determined using laboratory combustion hood.^hReferences 13-14.^jReference 7.

TABLE 11.1-4. EMISSION FACTORS FOR PRESCRIBED BURNING
BY U. S. REGION

Regional configuration and fuel type ^a	Percent of fuel ^b	Pollutant ^c			
		Particulate (g/kg)			CO
		PM _{2.5}	PM ₁₀	PM	
Pacific Northwest					
Logging slash					
Piled slash	42	4	5	6	37
Douglas fir/					
Western hemlock	24	12	13	17	175
Mixed conifer	19	12	13	17	175
Ponderosa pine	6	13	13	20	126
Hardwood	4	11	12	18	112
Underburning pine	5	30	30	35	163
Average for region	100	9.4	10.3	13.3	111.1
Pacific Southwest					
Sagebrush	35		9	15	62
Chaparral	20	8	9	15	62
Pinyon/Juniper	20		13	17	175
Underburning pine	15		30	35	163
Grassland	10		10	10	75
Average for region	100		13.0	17.8	101.0
Southeast					
Palmetto/gallberry	35		15	16	125
Underburning pine	30		30	35	163
Logging slash	20		13	20	126
Grassland	10		10	10	75
Other	5		17	17	175
Average for region	100		18.8	21.9	134
Rocky Mountain					
Logging slash	50		4	6	37
Underburning pine	20		30	35	163
Grassland	20		10	10	75
Other	10		17	17	175
Average for region	100		11.9	13.7	83.4
North Central and Eastern					
Logging slash	50		13	17	175
Grassland	30		10	10	75
Underburning pine	10		30	35	163
Other	10		17	17	175
Average for region	100		14	16.5	143.8

^aRegional areas are generalized, e. g., the Pacific Northwest includes Oregon, Washington and parts of Idaho and California. Fuel types generally reflect the ecosystems of a region, but users should seek advice on fuel type mix for a given season of the year. An average factor for Northern California could be more accurately described as chaparral, 25%; underburning pine, 15%; sagebrush, 15%; grassland, 5%; mixed conifer, 25%; and Douglas fir/Western hemlock, 15%.

Dash = no data.

^bBased on the judgment of forestry experts.

^cAdapted from Table 11.1-3 for the dominant fuel types burned.

References for Section 11.1

1. Development Of Emission Factors For Estimating Atmospheric Emissions From Forest Fires, EPA-450/3-73-009, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1973.
2. D. E. Ward and C. C. Hardy, Advances In The Characterization And Control Of Emissions From Prescribed Broadcast Fires Of Coniferous Species Logging Slash On Clearcut Units, EPA DW12930110-01-3/DOE DE-A179-83BP12869, U. S. Forest Service, Seattle, WA, January 1986.
3. L. F. Radke, et al., Airborne Monitoring And Smoke Characterization Of Prescribed Fires On Forest Lands In Western Washington and Oregon, EPA-600/X-83-047, U. S. Environmental Protection Agency, Cincinnati, OH, July 1983.
4. H. E. Mobley, et al., A Guide For Prescribed Fire In Southern Forests, U. S. Forest Service, Atlanta, GA, 1973.
5. Southern Forestry Smoke Management Guidebook, SE-10, U. S. Forest Service, Asheville, NC, 1976.
6. D. E. Ward and C. C. Hardy, "Advances In The Characterization And Control Of Emissions From Prescribed Fires", Presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, CA, June 1984.
7. C. C. Hardy and D. E. Ward, "Emission Factors For Particulate Matter By Phase Of Combustion From Prescribed Burning", Presented at the Annual Meeting of the Air Pollution Control Association Pacific Northwest International Section, Eugene, OR, November 19-21, 1986.
8. D. V. Sandberg and R. D. Ottmar, "Slash Burning And Fuel Consumption In The Douglas Fir Subregion", Presented at the 7th Conference On Fire And Forest Meteorology, Fort Collins, CO, April 1983.
9. D. V. Sandberg, "Progress In Reducing Emissions From Prescribed Forest Burning In Western Washington And Western Oregon", Presented at the Annual Meeting of the Air Pollution Control Association Pacific Northwest International Section, Eugene, OR, November 19-21, 1986.
10. R. D. Ottmar and D. V. Sandberg, "Estimating 1000-hour Fuel Moistures In The Douglas Fir Subregion", Presented at the 7th Conference On Fire And Forest Meteorology, Fort Collins, CO, April 25-28, 1983.
11. D. V. Sandberg, et al., Effects Of Fire On Air - A State Of Knowledge Review, WO-9, U. S. Forest Service, Washington, DC, 1978.
12. C. K. McMahon, "Characteristics Of Forest Fuels, Fires, And Emissions", Presented at the 76th Annual Meeting of the Air Pollution Control Association, Atlanta, GA, June 1983.
13. D. E. Ward, "Source Strength Modeling Of Particulate Matter Emissions From Forest Fires", Presented at the 76th Annual Meeting of the Air Pollution Control Association, Atlanta, GA, June 1983.

14. D. E. Ward, et al., "Particulate Source Strength Determination For Low-intensity Prescribed Fires", Presented at the Agricultural Air Pollutants Specialty Conference, Air Pollution Control Association, Memphis, TN, March 18-19, 1974.
15. Prescribed Fire Smoke Management Guide, 420-1, BIFC-BLM Warehouse, Boise, ID, February 1985.
16. Colin C. Hardy, Emission Factors For Air Pollutants From Range Improvement Prescribed Burning Of Western Juniper And Basin Big Sagebrush, PNW 88-575, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1990.

11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself, when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from open truck bodies.

11.2.6.2 Emissions And Correction Parameters¹⁻²

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles equal to or less than 75 microns in diameter) in the road surface material. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading. The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), may be estimated with a rating of B or D (see below), using the following empirical expression²:

$$E = 0.022 I \left(\frac{4}{n} \right) \left(\frac{s}{10} \right) \left(\frac{L}{280} \right) \left(\frac{W}{2.7} \right)^{0.7} \quad (\text{kg/VKT}) \quad (1)$$
$$E = 0.077 I \left(\frac{4}{n} \right) \left(\frac{s}{10} \right) \left(\frac{L}{1000} \right) \left(\frac{W}{3} \right)^{0.7} \quad (\text{lb/VMT})$$

where: E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR
PAVED ROADS AT INDUSTRIAL FACILITIES^a

Industry	No. of sites	No. of samples	Silt (wgt. %)		No. of travel lanes	Total loading x 10 ⁻³		Silt loading (g/m ²)	
			Range	Mean		Range	Mean	Range	Mean
Copper smelting	1	3	15.4 - 21.7	19.0	2	12.9 - 19.5 45.8 - 69.2	15.9 55.4	188 - 400	292
Iron and steel production	6	20	1.1 - 35.7	12.5	2	0.006 - 4.77 0.020 - 16.9	0.495 1.75	0.09 - 79	12
Asphalt batching	1	3	2.6 - 4.6	3.3	1	12.1 - 18.0 43.0 - 64.0	14.9 52.8	76 - 193	120
Concrete batching	1	3	5.2 - 6.0	5.5	2	1.4 - 1.8 5.0 - 6.4	1.7 5.9	11 - 12	12
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	2.8 - 5.5 9.9 - 19.4	3.8 13.3	53 - 95	70

^a References 1-5.

^b Multiply entries by 1,000 to obtain stated units.

11.2.7 INDUSTRIAL WIND EROSION

11.2.7.1 General¹⁻³

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter (cm) in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 meters per second (11 miles per hour) at 15 centimeters above the surface or 10 meters per second (22 miles per hour) at 7 meters above the surface, and (b) particulate emission rates tend to decay rapidly (half life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

11.2.7.2 Emissions And Correction Parameters

If typical values for threshold wind speed at 15 centimeters are corrected to typical wind sensor height (7-10 meters), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 miles per hour), matches well with the half life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \quad (1)$$

where u = wind speed, centimeters per second
 u^* = friction velocity, centimeters per second
 z = height above test surface, cm
 z_0 = roughness height, cm
 0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y intercept of the velocity profile, i. e., the height at which the wind speed is zero. These parameters are illustrated in Figure 11.2.7-1 for a roughness height of 0.1 centimeters.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

11.2.7.3 Predictive Emission Factor Equation⁴

The emission factor for wind generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter per year as follows:

$$\text{Emission factor} = k \sum_{i=1}^N P_i \quad (2)$$

where k = particle size multiplier
 N = number of disturbances per year
 P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the i th period between disturbances, g/m^2

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

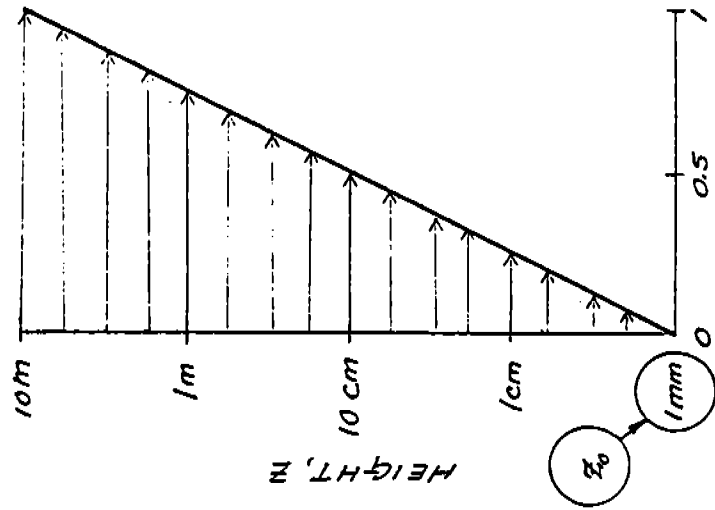
AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 2

<u>30 μm</u>	<u><15 μm</u>	<u><10 μm</u>	<u><2.5 μm</u>
1.0	0.6	0.5	0.2

This distribution of particle size within the under 30 micron fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, $N = 365$ per year, and for a surface disturbance once every 6 months, $N = 2$ per year.

SEMI-LOGARITHMIC REPRESENTATION



WIND SPEED AT z
WIND SPEED AT 10m

ARITHMETIC REPRESENTATION

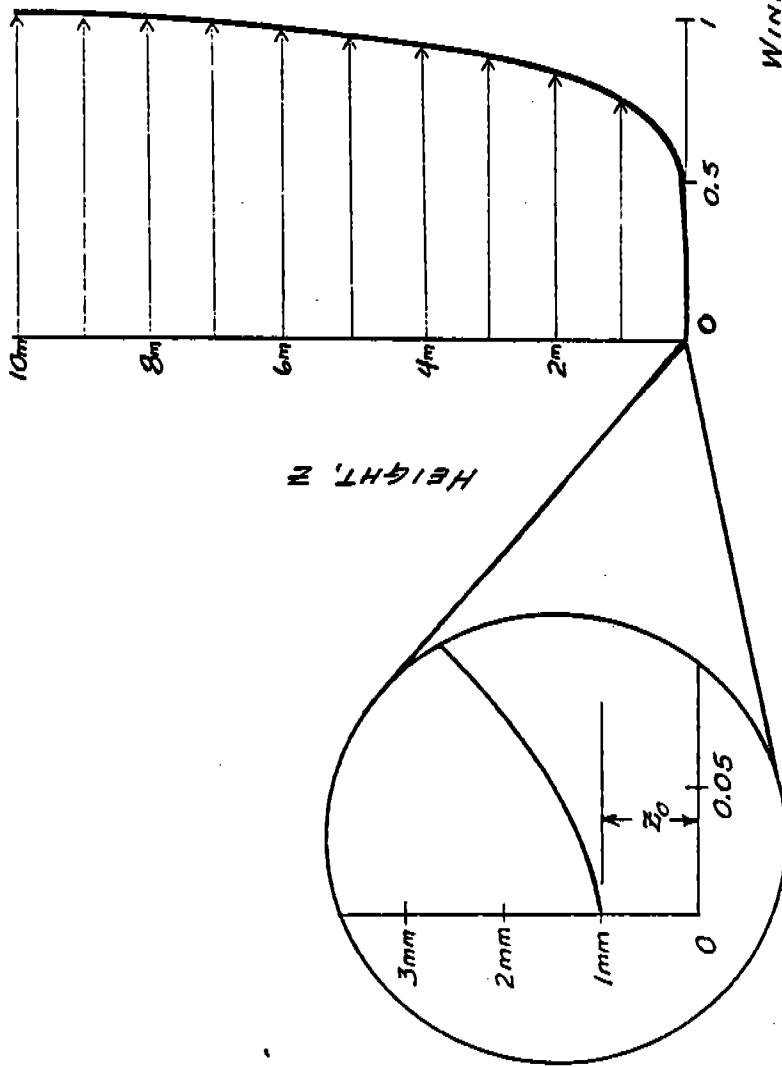


Figure 11.2.7-1. Illustration of logarithmic velocity profile.

The erosion potential function for a dry, exposed surface is:

$$P = 58 (u^* - u_t^*)^2 + 25 (u^* - u_t^*) \quad (3)$$

$$P = 0 \text{ for } u^* \leq u_t^*$$

where u^* = friction velocity (m/s)

u_t^* = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady state emission rates.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below in Table 11.2.7-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.⁵⁻⁶

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 11.2.7-2.

TABLE 11.2.7-1. FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY

Tyler sieve no.	Opening (mm)	Midpoint (mm)	u_t^* (cm/sec)
5	4	3	100
9	2	1.5	72
16	1	0.75	58
32	0.5	0.375	43
60	0.25		

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil):

1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.
2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm.
3. Pour the sample into the top sieve (4 mm opening), and place a lid on the top.
4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.
5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i. e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.
6. Determine the threshold friction velocity from Figure 1.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.⁷ These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10 meter reference height using Equation 1.

To convert the fastest mile of wind (u_{10}^+) from a reference anemometer height of 10 meters to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053 u_{10}^+ \quad (4)$$

where u^* = friction velocity (meters per second)

u_{10}^+ = fastest mile of reference anemometer for period
between disturbances (meters per second)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

TABLE 11.2.7-2. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)	
			$z_0 = \text{Act}$	$z_0 = 0.5 \text{ cm}$
Overburden ^a	1.02	0.3	21	19
Scoria (roadbed material) ^a	1.33	0.3	27	25
Ground coal ^a (surrounding coal pile)	0.55	0.01	16	10
Uncrusted coal pile ^a	1.12	0.3	23	21
Scraper tracks on coal pile ^{a, b}	0.62	0.06	15	12
Fine coal dust on concrete pad ^c	0.54	0.2	11	10

^aWestern surface coal mine. Reference 2.

^bLightly crusted.

^cEastern power plant. Reference 3.

If the pile significantly penetrates the surface wind layer (i. e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flat top, 37 degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.⁹ The results are shown in Figure 11.2.7-2 corresponding to an actual pile height of 11 meters, a reference (upwind) anemometer height of 10 meters, and a pile surface roughness height (z_0) of 0.5 centimeters. The measured surface winds correspond to a height of 25 centimeters above the surface. The area fraction within each contour pair is specified in Table 11.2.7-3.

The profiles of u_s/u_r in Figure 11.2.7-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u_{10}^+) using a variation of Equation 1:

$$u_{10}^+ = u^+ \frac{\ln(10/0.005)}{\ln(z/0.005)} \quad (5)$$

where a typical roughness height of 0.5 cm (0.005 meters) has been assumed. If a site specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 11.2.7-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u_s^+):

$$u_s^+ = \frac{(u_s)}{u_r} u_{10}^+ \quad (6)$$

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u^*):

$$u^* = \frac{0.4 u_s^+}{\frac{25}{\ln 0.5}} = 0.10 u_s^+$$

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Table 11.2.7-2 or determine from mode of aggregate size distribution).
2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u_{10}^+) using Equation 5.
4. Convert fastest mile values (u_{10}^+) to equivalent friction velocities (u^*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.
5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i. e., within the isopleth values of u_s/u_r in Figure 11.2.7-2 and Table 11.2.7-3) and determine the size of each subarea.
6. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3 and the emission factor using Equation 2.
7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hr emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

the full capacity of the pile. It is assumed that (a) the reclaiming operation disturbs only a limited portion of the surface area where the daily activity is occurring, such that the remainder of the pile surface remains intact, and (b) the topping off operation creates a fresh surface on the entire pile while restoring its original shape in the area depleted by daily reclaiming activity.

Because of the high frequency of disturbance of the pile, a large number of calculations must be made to determine each contribution to the total annual wind erosion emissions. This illustration will use a single month as an example.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 meters per second is obtained from Table 11.2.7-2.

Step 2: Except for a small area near the base of the pile (see Figure 11.2.7-3), the entire pile surface is disturbed every 3 days, corresponding to a value of $N = 120$ per year. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 11.2.7-4 shows a representative set of values (for a 1-month period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3-day periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 meters, so that a height correction to 10 meters is needed for the fastest mile values. From Equation 5,

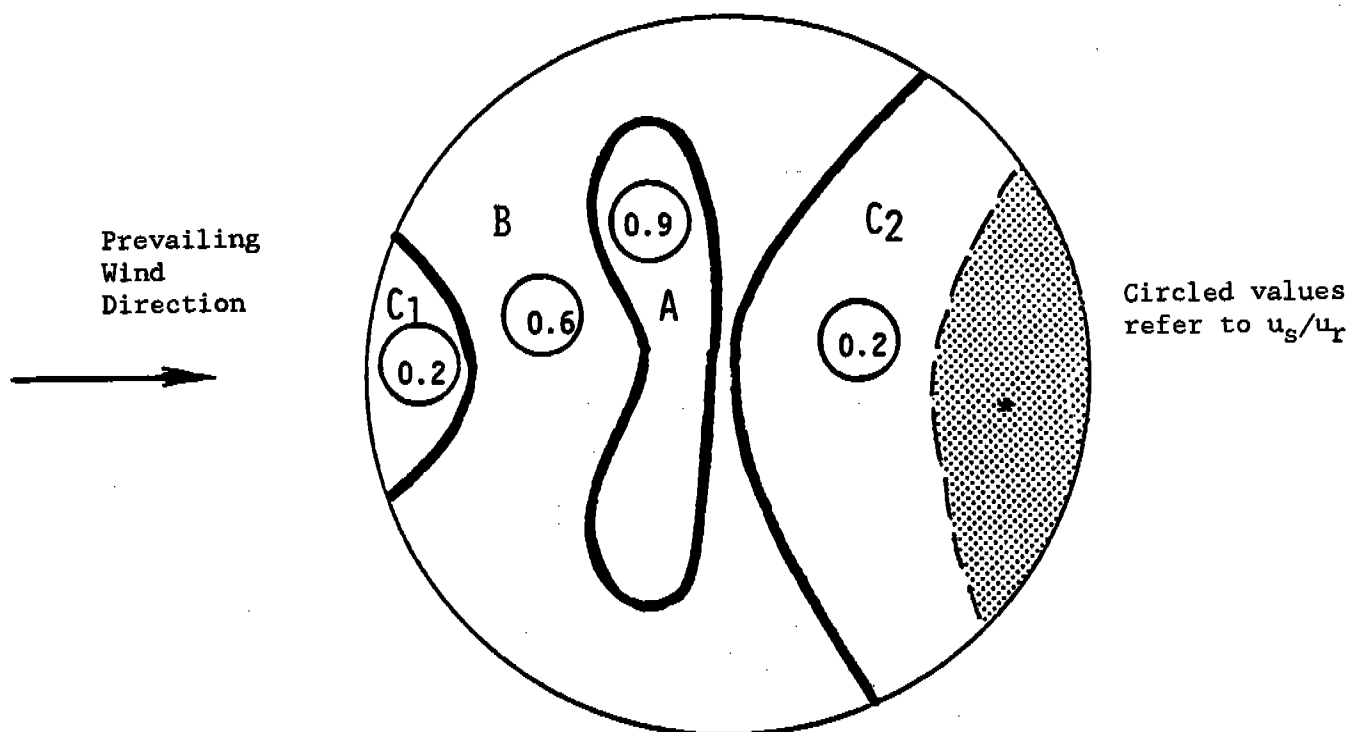
$$u_{10}^+ = u_7^+ \left(\frac{\ln (10/0.005)}{\ln (7/0.005)} \right)$$

$$u_{10}^+ = 1.05 u_7^+$$

Step 4: The next step is to convert the fastest mile value for each 3 day period into the equivalent friction velocities for each surface wind regime (i. e., u_s/u_r ratio) of the pile, using Equations 6 and 7. Figure 11.2.7-3 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 meters). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 11.2.7-4. As indicated, only three of the periods contain a friction velocity which exceeds the threshold value of 1.12 meters per second for an uncrusted coal pile. These three values all occur within the $u_s/u_r = 0.9$ regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the $u_s/u_r = 0.2$ regime) is never subject to wind speeds exceeding the threshold value.



* A portion of C_2 is disturbed daily by reclaiming activities.

Area ID	$\frac{u_s}{u_T}$	Pile Surface	
		%	Area (m^2)
A	0.9	12	101
B	0.6	48	402
$C_1 + C_2$	0.2	40	<u>335</u>
Total			838

Figure 11.2.7-3. Example 1: Pile surface areas within each wind speed regime.

As shown in Table 11.2.7-5, the results of these calculations indicate a monthly PM₁₀ emission total of 780 grams.

11.2.7.5 Example 2: Calculation for wind erosion from flat area covered with coal dust

A flat circular area of 29.2 meters in diameter is covered with coal dust left over from the total reclaiming of a conical coal pile described in the example above. The total exposed surface area is calculated as follows:

$$S = \frac{\pi}{4} d^2 = 0.785 (29.2)^2 = 670 \text{ m}^2$$

This area will remain exposed for a period of 1 month when a new pile will be formed.

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 0.54 m/s is obtained from Table 11.2.7-2.

Step 2: The entire surface area is exposed for a period of 1 month after removal of a pile and $N = 1/\text{yr}$.

Step 3: From Figure 11.2.7-4, the highest value of fastest mile for the 30-day period (31 mph) occurs on the 11th day of the period. In this example, the reference anemometer height is 7 m, so that a height correction is needed for the fastest mile value. From Step 3 of the previous example, $u_{10}^+ = 1.05 u_7^+$, so that $u_{10}^+ = 33 \text{ mph}$.

Step 4: Equation 4 is used to convert the fastest mile value of 33 mph (14.6 mps) to an equivalent friction velocity of 0.77 mps. This value exceeds the threshold friction velocity from Step 1 so that erosion does occur.

Step 5: This step is not necessary, because there is only one frequency of disturbance for the entire source area.

Steps 6 and 7: The PM₁₀ emissions generated by the erosion event are calculated as the product of the PM₁₀ multiplier ($k = 0.5$), the erosion potential (P) and the source area (A). The erosion potential is calculated from Equation 3 as follows:

$$\begin{aligned} P &= 58(u^* - u_t^*)^2 + 25(u^* - u_t^*) \\ P &= 58(0.77 - 0.54)^2 + 25(0.77 - 0.54) \\ &= 3.07 + 5.75 \\ &= 8.82 \text{ g/m}^2 \end{aligned}$$

Thus the PM₁₀ emissions for the 1 month period are found to be:

$$\begin{aligned} E &= (0.5)(8.82 \text{ g/m}^2)(670 \text{ m}^2) \\ &= 3.0 \text{ kg} \end{aligned}$$

References for Section 11.2.7

1. C. Cowherd Jr., "A New Approach To Estimating Wind Generated Emissions From Coal Storage Piles", Presented at the APCA Specialty Conference on Fugitive Dust Issues in the Coal Use Cycle, Pittsburgh, PA, April 1983.
2. K. Axtell and C. Cowherd, Jr., Improved Emission Factors For Fugitive Dust From Surface Coal Mining Sources, EPA-600/7-84-048, U. S. Environmental Protection Agency, Cincinnati, OH, March 1984.
3. G. E. Muleski, "Coal Yard Wind Erosion Measurement", Midwest Research Institute, Kansas City, MO, March 1985.
4. Update Of Fugitive Dust Emissions Factors In AP-42 Section 11.2 - Wind Erosion, MRI No. 8985-K, Midwest Research Institute, Kansas City, MO, 1988.
5. W. S. Chepil, "Improved Rotary Sieve For Measuring State And Stability Of Dry Soil Structure", Soil Science Society Of America Proceedings, 16:113-117, 1952.
6. D. A. Gillette, et al., "Threshold Velocities For Input Of Soil Particles Into The Air By Desert Soils", Journal Of Geophysical Research, 85(C10):5621-5630.
7. Local Climatological Data, National Climatic Center, Asheville, NC.
8. M. J. Changery, National Wind Data Index Final Report, HCO/T1041-01 UC-60, National Climatic Center, Asheville, NC, December 1978.
9. B. J. B. Stunder and S. P. S. Arya, "Windbreak Effectiveness For Storage Pile Fugitive Dust Control: A Wind Tunnel Study", Journal Of The Air Pollution Control Association, 38:135-143, 1988.



11.3 EXPLOSIVES DETONATION

11.3.1 General 1-5

This section deals mainly with pollutants resulting from the detonation of industrial explosives and firing of small arms. Military applications are excluded from this discussion. Emissions associated with the manufacture of explosives are treated in Section 5.6, Explosives.

An explosive is a chemical material that is capable of extremely rapid combustion resulting in an explosion or detonation. Since an adequate supply of oxygen cannot be drawn from the air, a source of oxygen must be incorporated into the explosive mixture. Some explosives, such as trinitrotoluene (TNT), are single chemical species, but most explosives are mixtures of several ingredients. "Low explosive" and "high explosive" classifications are based on the velocity of explosion, which is directly related to the type of work the explosive can perform. There appears to be no direct relationship between the velocity of explosions and the end products of explosive reactions. These end products are determined primarily by the oxygen balance of the explosive. As in other combustion reactions, a deficiency of oxygen favors the formation of carbon monoxide and unburned organic compounds and produces little, if any, nitrogen oxides. An excess of oxygen causes more nitrogen oxides and less carbon monoxide and other unburned organics. For ammonium nitrate and fuel oil mixtures (ANFO), a fuel oil content of more than 5.5 percent creates a deficiency of oxygen.

There are hundreds of different explosives, with no universally accepted system for classifying them. The classification used in Table 11.3-1 is based on the chemical composition of the explosives, without regard to other to other properties, such as rate of detonation, which relate to the applications of explosives but not to their specific end products. Most explosives are used in two-, three-, or four-step trains that are shown schematically in Figure 11.3-1. The simple removal of a tree stump might be done with a two-step train made up of an electric blasting cap and a stick of dynamite. The detonation wave from the blasting cap would cause detonation of the dynamite. To make a large hole in the earth, an inexpensive explosive such as ammonium nitrate and fuel oil (ANFO) might be used. In this case, the detonation wave from the blasting cap is not powerful enough to cause detonation, so a booster must be used in a three- or four-step train. Emissions from the blasting caps and safety fuses used in these trains are usually small compared to those from the main charge, because the emissions are roughly proportional to the weight of explosive used, and the main charge makes up most of the total weight. No factors are given for computing emissions from blasting caps or fuses, because these have not been measured, and because the uncertainties are so great in estimating emissions from the main and booster charges that a precise estimate of all emissions is not practical.

11.3.2 Emissions And Controls 2,4-6

Carbon monoxide is the pollutant produced in greatest quantity from explosives detonation. TNT, an oxygen deficient explosive, produces more CO than most dynamites, which are oxygen balanced. But all explosives produce measurable amounts of CO. Particulates are produced as well, but such large quantities of particulate are generated in the shattering of the rock and earth by the explosive that the quantity of particulates from the explosive charge cannot be distinguished. Nitrogen oxides (both NO and NO₂) are formed, but only limited data are available on these emissions. Oxygen deficient explosives are said to produce little or no nitrogen oxides, but there is only a small body of data to confirm this. Unburned hydrocarbons also result from explosions, but in most instances, methane is the only species that has been reported.

Hydrogen sulfide, hydrogen cyanide and ammonia all have been reported as products of explosives use. Lead is emitted from the firing of small arms ammunition with lead projectiles and/or lead primers, but the explosive charge does not contribute to the lead emissions.

The emissions from explosives detonation are influenced by many factors such as explosive composition, product expansion, method of priming, length of charge, and confinement. These factors are difficult to measure and control in the field and are almost impossible to duplicate in a laboratory test facility. With the exception of a few studies in underground mines, most studies have been performed in laboratory test chambers that differ substantially from the actual environment. Any estimates of emissions from explosives use must be regarded as approximations that cannot be made more precise, because explosives are not used in a precise, reproducible manner.

To a certain extent, emissions can be altered by changing the composition of the explosive mixture. This has been practiced for many years to safeguard miners who must use explosives. The U. S. Bureau of Mines has a continuing program to study the products from explosives and to identify explosives that can be used safely underground. Lead emissions from small arms use can be controlled by using jacketed soft point projectiles and special leadfree primers.

Emission factors are given in Table 11.3-1.

References for Section 11.3

1. C. R. Newhouser, Introduction to Explosives, National Bomb Data Center, International Association of Chiefs of Police, Gaithersburg, MD (undated).
2. Roy V. Carter, "Emissions from the Open Burning or Detonation of Explosives", Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

3. Melvin A. Cook, The Science of High Explosives, Reinhold Publishing Corporation, New York, 1958.
4. R. F. Chaiken, et al., Toxic Fumes from Explosives: Ammonium Nitrate Fuel Oil Mixtures, Bureau of Mines Report of Investigations 7867, U. S. Department of Interior, Washington, DC, 1974.
5. Sheridan J. Rogers, Analysis of Noncoal Mine Atmospheres: Toxic Fumes from Explosives, Bureau of Mines, U. S. Department of Interior, Washington, DC, May 1976.
6. A. A. Juhasz, "A Reduction of Airborne Lead in Indoor Firing Ranges by Using Modified Ammunition", Special Publication 480-26, Bureau of Standards, U. S. Department of Commerce, Washington, DC, November 1977.



TABLE C.2-1. PARTICLE SIZE CATEGORY BY AP-42 SECTION

AP-42 Section	Source Category	Category Number*	AP-42 Section	Source Category	Category Number*
	External combustion		6.8	Ammonium nitrate fertilizers	a
1.1	Bituminous and subbituminous coal combustion	a	6.10	Phosphate fertilizers	3
1.2	Anthracite coal combustion	a	6.10.3	Ammonium phosphates	4
1.3	Fuel oil combustion			Reactor/ammoniator-granulator	4
	Residual oil			Dryer/cooler	7
	Utility	a	6.11	Starch manufacturing	a
	Industrial	a	6.14	Urea	6
	Commercial	a	6.16	Defoliation and harvesting of cotton	6
	Distillate oil			Trailer loading	6
	Utility	a	6.17	Harvesting of grain	6
	Commercial	a		Harvesting machine	6
	Residential	a		Truck loading	6
1.4	Natural gas combustion	a	6.18	Field transport	6
1.5	Liquefied petroleum gas	a		Ammonium sulfate	b
1.6	Wood waste combustion			Rotary dryer	b
	in boilers	a		Fluidized bed dryer	
1.7	Lignite combustion	a	7.1	Metallurgical	
1.8	Bagasse combustion	b		Primary aluminum production	4
1.9	Residential fireplaces	a		Bauxite grinding	5
1.10	Residential wood stoves	a		Aluminum hydroxide calcining	9
1.11	Waste oil combustion	a		Anode baking furnace	a
	Solid waste disposal			Prebake cell	8
2.1	Refuse combustion	a		Vertical Soderberg	a
2.3	Conical burners (wood waste)	2	7.2	Horizontal Soderberg	a
2.5	Sewage sludge incineration	a	7.3	Coke manufacturing	a
	Internal combustion engines		7.4	Primary copper smelting	a
	Highway vehicles	c	7.5	Ferroalloy production	a
3.2	Off highway vehicles	1		Iron and steel production	
	Chemical processes			Blast furnace	a
5.4	Charcoal	9		Slips	a
5.8	Hydrofluoric acid			Cast house	a
	Spar drying	3		Sintering	a
	Spar handling	3		Windbox	a
	Transfer	3	7.6	Sinter discharge	a
5.10	Paint and varnish	4	7.7	Basic oxygen furnace	a
5.11	Phosphoric acid (thermal process)	a	7.8	Electric arc furnace	a
5.12	Phthalic anhydride	9		Primary lead smelting	a
5.15	Soap and detergents	a		Zinc smelting	8
5.16	Sodium carbonate	a		Secondary aluminum operations	8
5.17	Sulfuric acid	b		Sweating furnace	8
	Food and agricultural		7.9	Smelting	8
6.1	Alfalfa dehydrating			Crucible furnace	a
	Primary cyclone	b	7.10	Reverberatory furnace	8
	Meal collector cyclone	7	7.11	Secondary copper smelting	8
	Pellet cooler cyclone	7	7.12	and alloying	a
	Pellet regrind cyclone	7	7.13	Gray iron foundries	a
6.2	Coffee roasting	6	7.14	Secondary lead Processing	8
6.3	Cotton ginning	b	7.15	Secondary magnesium smelting	b
6.4	Grain elevators and processing plants	a	7.16	Steel foundries - melting	8
6.5	Fermentation	6,7	7.17	Secondary zinc processing	b
6.7	Meat smokehouses	9	7.18	Storage battery production	4
				Leadbearing ore crushing and grinding	

*Data for numbered categories are given in Table C.2-2. Particle size data on "a" categories are found in the AP-42 text; for "b" categories, in Appendix C.1; and for "c" categories, in AP-42 Volume II: Mobile Sources.

))

))

))

APPENDIX D

PROCEDURES FOR SAMPLING SURFACE/BULK DUST LOADING

Procedures are herein recommended for collection of road dust and aggregate material samples from unpaved and paved industrial roads, and from storage piles. These recommended procedures are based on a review of American Society Of Testing And Materials (ASTM) standards. The recommended procedures follow ASTM standards where practical, and where not, an effort has been made to develop procedures consistent with the intent of the majority of pertinent ASTM Standards.

1. Unpaved Industrial Roads

The main objective in sampling the surface material from unpaved roads is to collect composite samples from major road segments within an industrial facility. A composite, or gross, sample comprises of several incremental samples collected from representative subareas of the source. A road segment can be defined as the distance between major intersections. Major road segments can be identified by an analysis of plant delivery, shipment and employee travel routes and should be mapped before sampling begins.

The goal of this sampling procedure is to develop data on the mean silt and moisture contents of surface material from a given road segment. "Representative" samples will be collected and analyzed through the use of compositing and splitting techniques. A composite sample is formed by the collection and subsequent mixing of the combined mass obtained from multiple increments or grabs of the material in question. The analyzed, or test, sample refers to the reduced quantity of material extracted, or split, from the larger field sample. A minimum of 0.4 kg (~1 lb) of sample is required for analysis of the silt fraction and moisture content.

A gross sample of 5 kg (10 lb) to 23 kg (50 lb) from every unpaved road segment should be collected in a clean, labeled, 19 liter (5 gal) plastic pail with a sealable poly liner. This sample should be composited from a minimum of three incremental samples, but it may consist of only one, depending on the length of the road segment and hazards to the sampling team. The first sample increment is collected at a random location within the first 0.8 km (0.5 mi) of the road segment, with additional samples collected from each remaining 0.8 km (0.5 mi) of the road segment up to a maximum road segment length of 4.8 km (3 mi).

An acceptable method of selecting three sample locations on road segments of less than 1.5 mi length is to sample at locations represented by three random numbers (x_1 , x_2 , x_3), between 0.0 mi and y mi, the road segment length. A scientific handheld calculator can produce pseudorandom numbers, or they may be obtained from statistical tables.

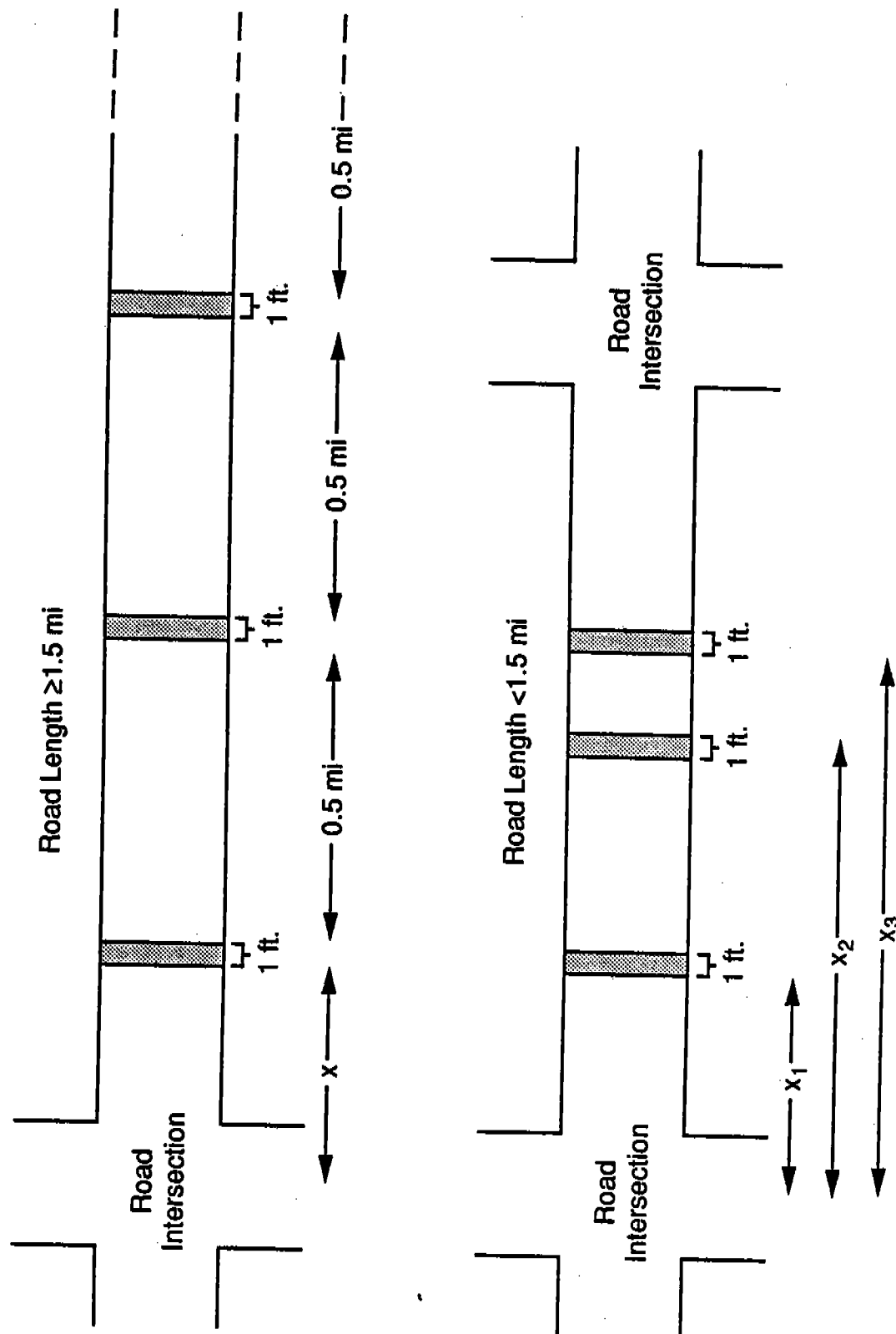


Figure 1. Recommended Sampling Locations for an Industrial Unpaved Road

Sampling Data for Unpaved Roads

Date Sample Collected _____ Recorded by _____

Type of Material Sampled: _____
 Site of Sampling*: _____

SAMPLING METHOD

1. Sampling device: whisk broom and dust pan
2. Sampling depth: loose surface material (do not abrade road base)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
 - (a) 1 sample of 23kg (50 lb) minimum for every 4.8 km (3 mi) sampled
 - (b) composite of at least 3 increments: lateral strips of 30 cm (1 ft) width extending over traveled portion of roadway

Indicate deviations from above methods and general meteorology: _____

SAMPLING DATA

Sample No.	Time	Location*	Surface Area	Depth	Quantity of Sample

* Use code given on plant or road map for segment identification and indicate sample on map.

Figure 2. Data Form For Unpaved Road Sampling.

Figure 1 illustrates sampling locations along industrial unpaved roads. The width of each sampled area across the road should be 0.3 m (1 ft). Only the travelled section of the roadway should be sampled.

The loose surface material is removed from the hard road base with a whisk broom and dustpan. The material should be swept carefully to prevent injection of fine dust into the atmosphere. The hard road base below the loose surface material should not be abraded so as to generate more fine material than exists on the road in its natural state. Figure 2 is a data form to be used for the sampling of unpaved roads.

2. Paved Industrial Roads

For paved roads, it is necessary to obtain a representative sample of loading (mass/area) from the travelled surface to characterize particulate emissions caused by vehicle traffic. A composite sample should be collected from each major road segment in the plant. A minimum sample mass of 0.4 kg (~1 lb) should be composited from a minimum of three separate increments.

Figure 3 is a diagram showing the locations of incremental samples for a two-lane paved industrial road. The first sample increment should be collected at a random location between 0.0 and 0.8 km (0.5 mi). Additional samples should be collected from each remaining 0.8 km (0.5 mi) of the road segment, up to a maximum road segment length of 8 km (5 mi). For road segments of less than 2.4 km (1.5 mi) in length, an acceptable method would be to collect sample increments at three randomly chosen locations (x_1 , x_2 , x_3), between 0.0 km and y km, the road length.

Care must be taken that sampled dust loadings are typical of only the travelled portion of the road segment of interest. On paved roads painted with standard markings, the area from "solid white line to solid white line" should be sampled. Curbs should not be sampled, since vehicles are not likely to disturb dust from this area.

Each incremental sample location consists of a lateral strip from 0.3 to 3 m (1 to 10 ft) wide across the travelled portion of the roadway. The exact area to be sampled depends on the amount of loose surface material on the paved roadway. For a visibly dirty road, a width of 0.3 m (1 ft) is sufficient, but for a visibly clean road, a width of 3 m (10 ft) could be required to obtain an adequate sample.

This sampling procedure is the preferred method of collecting surface dust from a paved industrial road segment. However, if for lack of resources or traffic hazards collection of a minimum of three sample increments across all travel lanes is not feasible on a short road segment (<2.4 km or 1.5 mi), sampling from a single representative paved strip 3 to 9 m (10 to 30 ft) wide across each lane will likely produce sufficient sample for analysis.

Samples are removed from the road surface by vacuuming, preceded by broom sweeping if large aggregate is present. The sample number is identified and the sampled area measured and is recorded on the appropriate data form. With a whisk broom and a dust pan, the larger particles are collected from the sampling area and placed in a clean, labeled plastic jar. The remaining

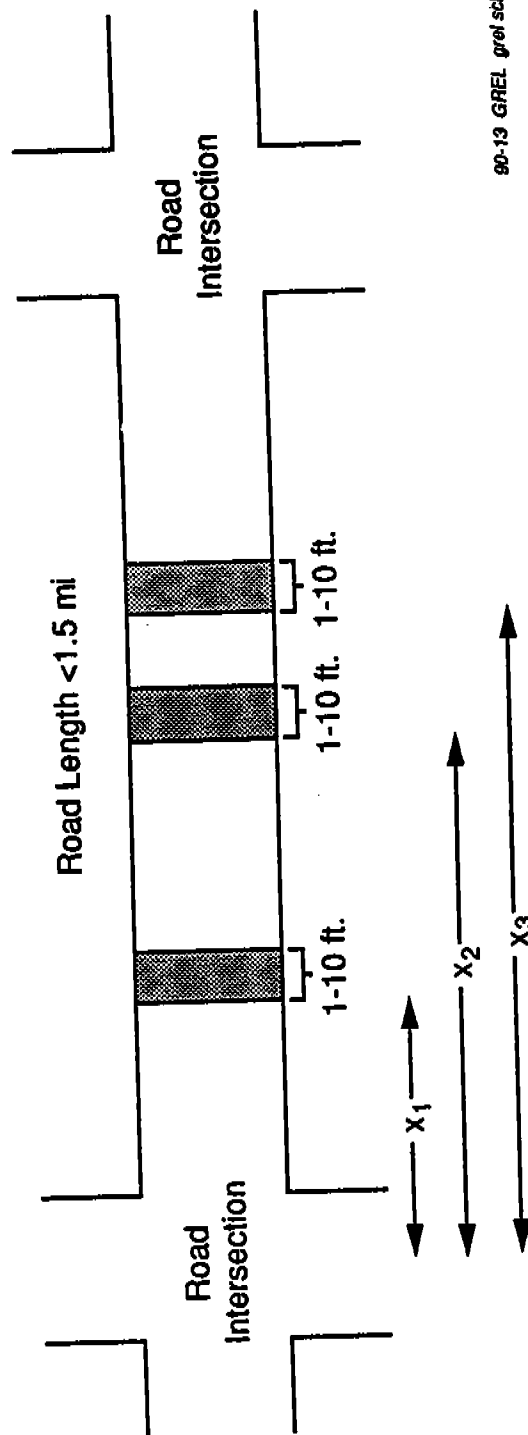
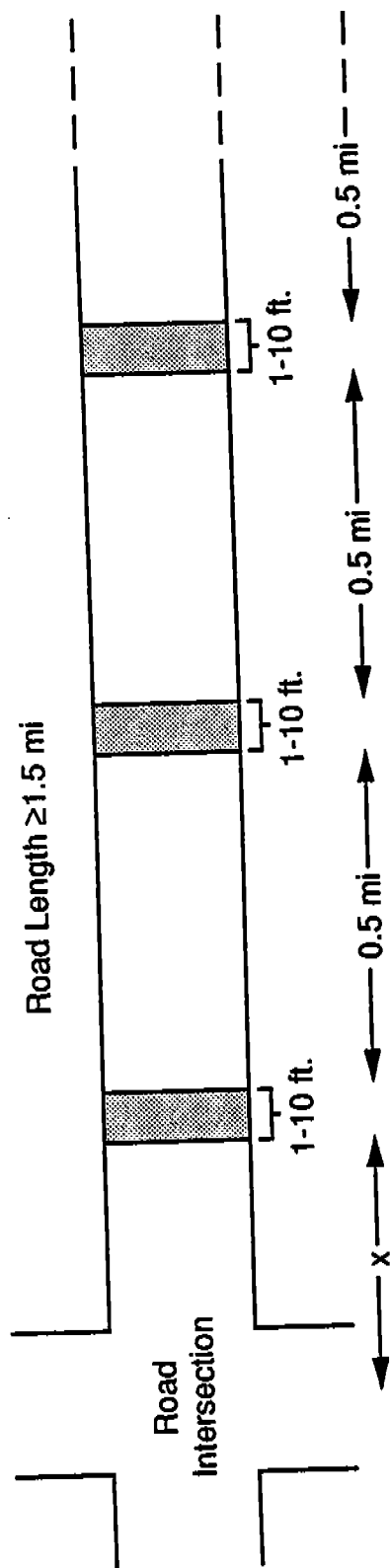


Figure 3. Recommended Sampling Locations for an Industrial Paved Road

Paved Road Loading

Date Sample Collected _____ Recorded by _____

Type of Material Sampled: _____ No. of Traffic Lanes: _____
 Sampling Location*: _____ Surface Condition: _____

*Use code given on plant or road map for segment identification and indicate sample on map.
SAMPLING METHOD

1. Sampling device: portable vacuum cleaner (broom sweep first if loading is heavy)
2. Sampling depth: loose surface material
3. Sample container: tared and numbered vacuum cleaner bags
4. Gross sample specifications:
 - (a) 1 sample every 8 km (5 mi) of road length
 - (b) lateral sampling strips of 30 cm (1 ft) minimum width extending from curb to curb traveled portion of roadway
 - (c) do not sample curb areas

Indicate deviations from above method: _____

SAMPLING DATA

Sample No.	Vac Bag	Time	Surface Area	Broom Swept?

Sample No.	Vac Bag	Time	Surface Area	Broom Swept?

DIAGRAM (mark each segment with vacuum bag number)

Figure 4. Data Form For Paved Road Sampling.

Sampling Data for Storage Piles	
Date Sample Collected _____	Recorded by _____

Type of Material Sampled: _____
Site of Sampling: _____

1. Sampling device: pointed shovel
2. Sampling depth: 10-15 cm (4-6 in)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
 - (a) 1 sample of 23kg (50 lb) minimum for every pile sampled
 - (b) composite of 10 increments
5. Minimum portion of stored material (at one site) to be sampled: 25%

[illegible]

9/90

smaller particles are then swept from the road with an electric broom-type vacuum sweeper. The sweeper must be equipped with an empty weighed, labeled, disposable vacuum bag. Care must be taken to avoid tearing the bag and losing the sample. After the sample has been collected, the bag should be removed from the sweeper, checked for leaks and stored in a previously labeled sealed plastic bag or paper envelope for transport. Figure 4 presents a data form to be used for the sampling of paved roads.

3. Storage Piles

Ideally, a gross sample made up of top, middle, and bottom incremental samples from a pile should be obtained to determine representative silt and moisture content for use in predicting particulate emissions from wind erosion and materials handling operations. However, it is impractical to climb to the top or even the middle of most industrial storage piles, because of their large size.

The most practical approach to minimize sampling location bias for large piles is to sample as near to the middle of the pile as practical and to select sampling locations in a random fashion. A minimum of ten incremental samples should be obtained at locations along the entire perimeter of a large pile. If a small pile is sampled, two sets of three incremental samples should be collected from the pile top, middle, and bottom. A gross sample of 5 kg (10 lb) to 23 kg (50 lb) from a storage pile should be placed in a clean, labeled, 19 liter (5 gal) plastic pail with a sealable poly liner.

For determination of wind erosion estimation parameters, incremental samples are collected by skimming the surface of the pile in an upwards direction, using a straight-point shovel or small garden spade. Every effort must be made not to avoid sampling larger pieces of aggregate material.

To characterize a pile for particulate emissions from materials handling processes, incremental samples should be taken from the portion of the storage pile surface (1) which has been recently formed by the addition of aggregate material, or (2) from which aggregate material is being reclaimed. Samples should be collected with a shovel to a depth of 10 to 15 cm (4 to 6 in), taking care not to avoid sampling larger pieces of material.

If an inactive pile is to be sampled before loadout operations, sample increments should be obtained using a sampling tube approximately 2 m (6 ft) long pushed to a depth of 1 m (3 ft). The diameter of the sampling tube should be a minimum of 10 times the diameter of the largest particle sampled.

Samples should be representative of the interior portions of the pile that constitute the bulk of the material to be transferred. Figure 5 presents a data form to be used for the sampling of storage piles.

APPENDIX E

PROCEDURES FOR LABORATORY ANALYSIS OF SURFACE/BULK DUST LOADING SAMPLES

1.0 Samples From Sources Other Than Paved Roads

1.1 Sample Preparation

Once the gross sample is brought to the laboratory, it must be prepared for analyses of moisture and silt, the two physical parameters of principal interest. The latter is defined as the percent of test sample mass passing a 200 mesh screen (<75 micrometers physical diameter) based on mechanical sieving of oven-dried material. These analyses entail dividing the sample to a workable size.

The gross sample can be divided by using (1) mechanical devices, (2) alternative shovel method, (3) riffle, or (4) coning and quartering method. Mechanical division devices are not discussed in this section since they are not found in many laboratories. The alternative shovel method is actually only necessary for samples weighing hundreds of pounds. Therefore, only the use of the riffle and the coning and quartering method are discussed.

American Society For Testing And Materials (ASTM) standards describe the selection of the correct riffle size and the correct use of the riffle. Riffle slot widths should be at least three times the size of the largest aggregate in the material being divided. Figure 1 shows two riffles for sample division. The following describes the use of the riffle.

Divide the gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure 1, (a) and (b). Pass the material through the riffle from a feed scoop, feed bucket, or riffle pan having a lip or opening the full length of the riffle. When using any of the above containers to feed the riffle, spread the material evenly in the container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into the riffle pans, one-half of the sample being collected in a pan. Under no circumstances shovel the sample into the riffle, or dribble into the riffle from a small-mouthed container. Do not allow the material to build up in or above the riffle slots. If it does not flow freely through the slots, shake or vibrate the riffle to facilitate even flow.¹

The procedure for coning and quartering is best illustrated in Figure 2. Coning and quartering is a simple procedure which is applicable to all powdered materials and to sample sizes ranging from a few grams to several hundred pounds.² Oversized material, defined as >0.6 mm (3/8 in) in diameter, should be removed prior to quartering and weighed in a tared container. The following steps describe the procedure.

1. Mix the material and shovel it into a neat cone;
2. Flatten the cone by pressing the top without further mixing;
3. Divide the flat circular pile into equal quarters by cutting or scraping out two diameters at right angles;
4. Discard two opposite quarters;
5. Thoroughly mix the two remaining quarters, shovel them into a cone, and repeat the quartering and discarding procedures until the sample has been reduced to 0.4 to 1.8 kg (1 to 4 lb).

Preferably, the coning and quartering operation should be conducted on a floor covered with clean 10 mil plastic. Samples likely to be affected by moisture or drying must be handled rapidly, preferably in an area with a controlled atmosphere, and sealed in a container to prevent further changes during transportation and storage. Care must be taken that the material is not contaminated by anything on the floor or that a portion is not lost through cracks or holes.

The size of the laboratory sample is important. Too little sample will not be representative and too much sample will be unwieldy. Ideally, one would like to analyze the entire gross sample in batches, but this is not practical. While all ASTM standards acknowledge this impracticality, they disagree on the exact size, as indicated by the range of recommended samples, extending from 0.05 to 27 kg (0.1 to 60 lb).

The main principle in sizing the laboratory sample is to have sufficient coarse and fine portions to be representative of the material and to allow sufficient mass on each sieve so that the weighing is accurate. A laboratory sample of 400 to 1600 g is recommended since these masses can be handled by the scales normally available (1.6 to 2.6 kg capacities). Also, more sample than this can produce screen blinding for the 20 cm (8 in) diameter screens normally available. In addition, the sample mass should be such that it can be spread out in a reasonably sized drying pan to a depth of < 2.5 cm (1 in).

1.2 Laboratory Analysis Of Samples For Moisture And Silt Contents

The basic recommended procedure for silt analysis is mechanical, dry sieving after moisture analysis. Step-by-step procedures are given in Tables 1 and 2. The moisture content is obtained from a differential weight analysis of the bulk material before and after drying.

Non-organic samples should be oven dried overnight at 110° C (230°F) before sieving. The sieving time is variable; sieving should be conducted for several periods of equal interval (e. g., 10 min), and continued until the net sample weight collected in the pan increases by less than 3.0 percent of the previous silt weight. A small variation of 3.0 percent is allowed since some sample grinding due to interparticle abrasion will occur, and consequently, the weight will continue to increase.

When the silt mass change reduces to not more than 3.0 percent, it is thought that the natural silt has been passed through the No. 200 sieve screen and that any additional increase is due to grinding. The sample preparation

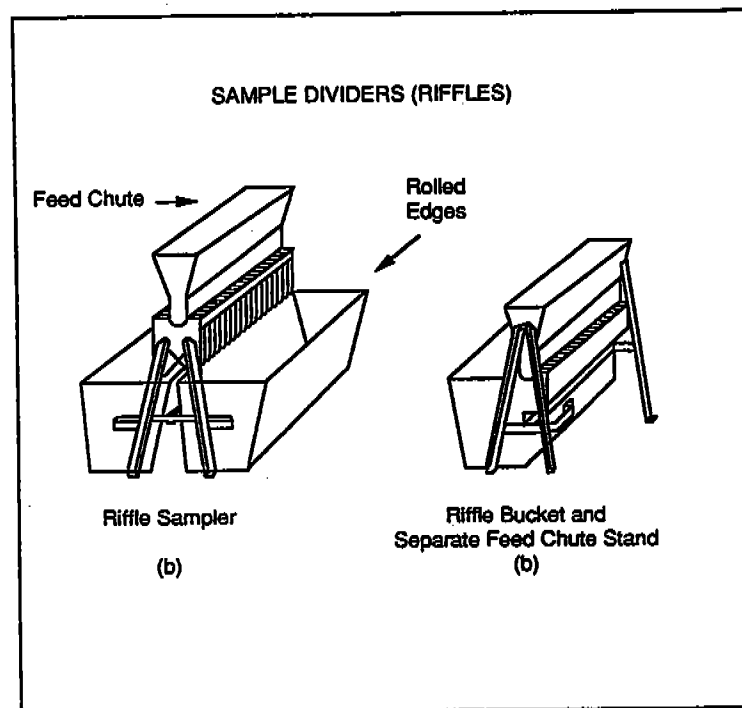


Figure 1. Sample Dividers (Riffles).

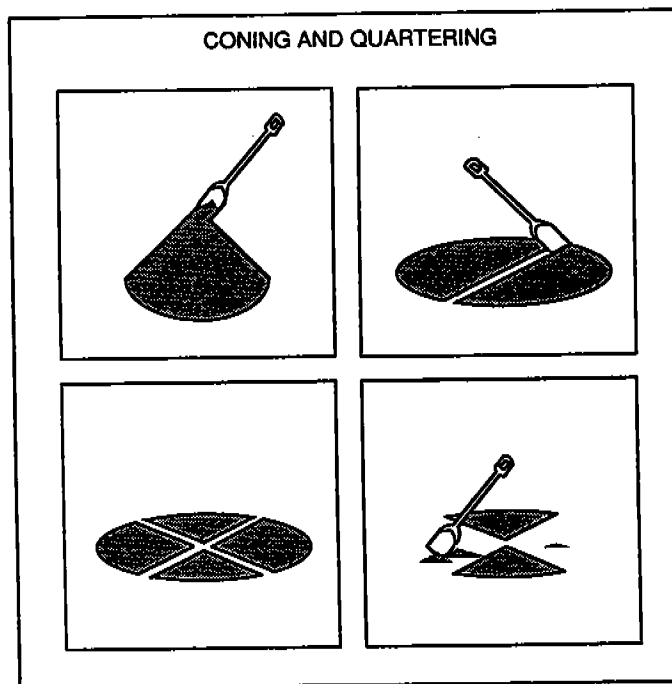


Figure 2. Procedure For Coning And Quartering.

MOISTURE ANALYSIS

Date: _____	By: _____
Sample No: _____	Oven Temperature: _____
Material: _____	Date In _____ Date Out _____
	Time In _____ Time Out _____
Split Sample Balance:	Drying Time _____
Make _____	
Capacity _____	Material Weight (after drying)
Smallest Division _____	Pan + Material: _____
	Pan: _____
Total Sample Weight: _____	Dry Sample: _____
(Excl. Container)	
Number of Splits: _____	MOISTURE CONTENT:
	(A) Wet Sample Wt. _____
Split Sample Weight (before drying)	(B) Dry Sample Wt. _____
Pan + Sample: _____	(C) Difference Wt. _____
Pan: _____	
Wet Sample: _____	$\frac{C \times 100}{A} = \text{_____ \% Moisture}$

Figure 3. Example Moisture Analysis Form.

operations and the moisture and sieving results can be recorded on the data forms shown in Figures 3 and 4.

2.0 Samples From Paved Roads

2.1 Sample Preparation And Analysis For Total Loading

The gross sample of paved road dust can arrive at the laboratory in two types of containers, (a) for heavily loaded roads, the broom swept particles will be in plastic jars; and (b) the vacuum swept dust will be in vacuum bags sealed inside plastic bags or paper envelopes. The broom swept particles and the vacuum swept dust are individually weighed on a beam balance. The broom swept particles are weighed in a tared container. The vacuum swept dust is weighed in the vacuum bag which was tared in the laboratory before going to the field.

The total surface dust loading on the traveled lanes of the paved road is then calculated in units of kilograms of dust on the traveled lanes per kilometer of road. The total dust loading on the traveled lanes is calculated as follows:

$$L = \frac{m_b + m_v}{P} \quad (1)$$

where: m_b = mass of the broom swept dust (kg)
 m_v = mass of the vacuum swept dust (kg)
 P = width of the sampling strip as measured along the centerline of the road segment (km)

TABLE E-1. MOISTURE ANALYSIS PROCEDURE

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.
2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before each weighing.
3. Record the make, capacity, and smallest division of the scale.
4. Weigh the laboratory sample(s) in the container(s).^a Record the combined weight(s). Check zero before each weighing.
5. Place sample in oven and dry overnight.^b
6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero reading on the balance before weighing.
7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.
8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

^aFor materials with high moisture content, agitate the sample container to ensure that any standing moisture is included in the laboratory sample container.

^bMaterials composed of hydrated minerals or organic material like coal and certain soils should be dried for only 1.5 h.

SILT ANALYSIS

Date _____

Sample No: _____

Material: _____

Split Sample Balance: _____

Make _____

Capacity _____

Smallest Division _____

By _____

Material Weight (after drying) _____

Pan + Material: _____

Pan: _____

Dry Sample: _____

Final Weight: _____

$$\% \text{ Silt} = \frac{\text{Net Weight } < 200 \text{ Mesh}}{\text{Total Net Weight}} \times 100 = _____\%$$

SIEVING

Time: Start:	Weight (Pan Only)
Initial (Tare):	
20 min:	
30 min:	
40 min:	

Screen	Tare Weight (Screen)	Final Weight (Screen + Sample)	Net Weight (Sample)	%
3/8 in.				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Figure 4. Example Silt Analysis Form.

TABLE E-2. SILT ANALYSIS PROCEDURES

1. Select the appropriate 8-in diameter, 2-in deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in, No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particulate sieve during sieving indicates that an intermediate sieve should be inserted.
2. Obtain a mechanical sieving device such as vibratory shaker or a Roto-Tap (without the tapping function).
3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4. Obtain a scale (capacity of at least 1600 g) and record make, capacity, smallest division, date of last calibration, and accuracy.
5. Tare sieves and pan. Check the zero before every weighing. Record weights.
6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. The sample should weigh between 400 and 1600 g (~0.9 to 3.5 lb)^a. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0 percent. Do not sieve longer than 40 min.
8. Weigh each sieve and its contents and record the weight. Check the zero reading on the balance before every weighing.
9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.
10. Calculate the percent of mass less than the 200 mesh screen (75 μ m). This is the silt content.

^aThis amount will vary for finely textured materials; 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve.

2.2 Sample Preparation And Analysis For Road Dust Silt Content

After weighing the sample to calculate total surface dust loading on the traveled lanes, the broom swept particles and vacuum swept dust are

composited. The composited sample is usually small and may require no sample splitting in preparation for sieving. If splitting is necessary to prepare a laboratory sample of 400 to 1600 g, the techniques discussed in Section 1.1 can be used. The laboratory sample is then sieved using the techniques described in part 1.2 above.

References For Appendix E

1. "Standard Method Of Preparing Coal Samples For Analysis", D2013-72, Annual Book Of ASTM Standards, 1977.
2. L. Silverman, et al., Particle Size Analysis In Industrial Hygiene, Academic Press, New York, 1971.

TECHNICAL REPORT DATA <i>(Please read Instructions on the reverse before completing)</i>		
1. REPORT NO. AP-42 Supplement C	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Supplement C to Compilation Of Air Pollutant Emission Factors, AP-42, Fourth Edition		5. REPORT DATE September 1990
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Environmental Protection Agency Office Of Air And Radiation Office Of Air Quality Planning And Standards Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES EPA Editor: Whitmel M. Joyner		
16. ABSTRACT In this Supplement to the Fourth Edition of AP-42, new or revised emissions data are presented for Residential Wood Stoves; Refuse Combustion; Sewage Sludge Incineration; Magnetic Tape Manufacturing Industry; Surface Coating Of Plastic Parts For Business Machines; Synthetic Fiber Manufacturing; Primary Lead Smelting; Gray Iron Foundries; Chemical Wood Pulping; Wildfires And Prescribed Burning; Industrial Paved Roads; Industrial Wind Erosion; Explosives Detonation; Appendix C.2, "Generalized Particle Size Distributions"; Appendix D, "Procedures For Sampling Surface/Bulk Dust Loading"; and Appendix E, "Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples".		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Stationary Sources Point Sources Area Sources Emission Factors Emissions		
18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES 170
	20. SECURITY CLASS (This page)	22. PRICE